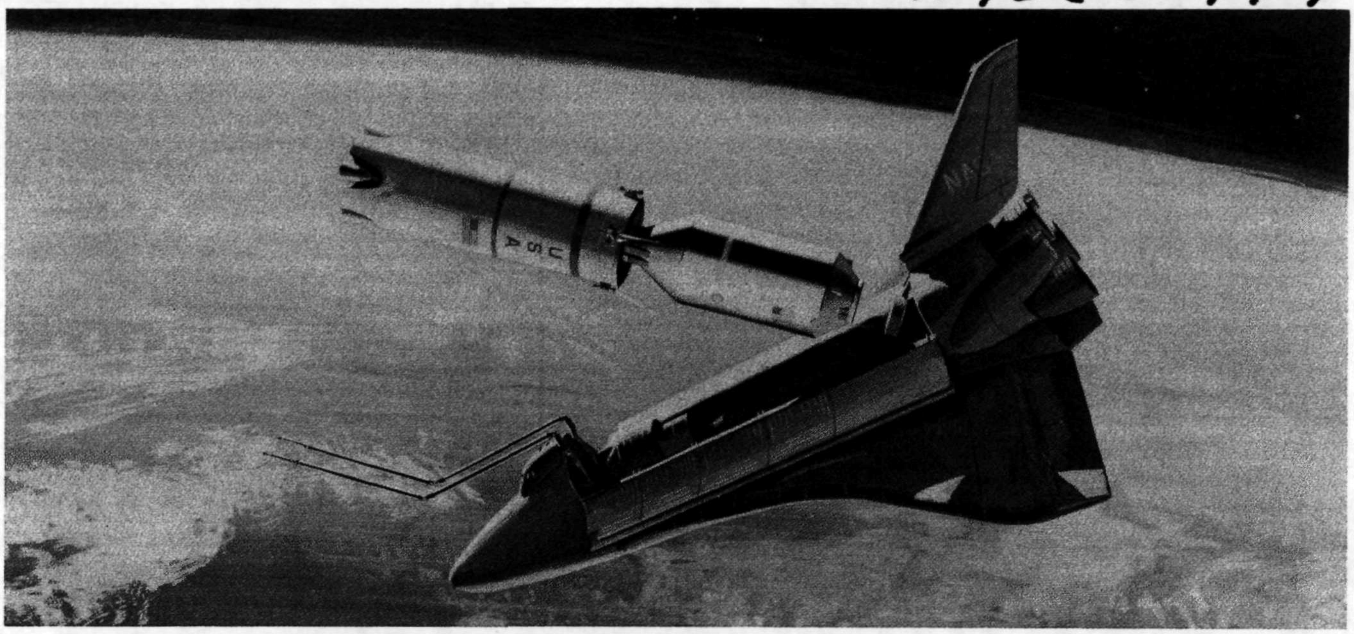
CONTRACT NAS8-27692
DR NO: MA-05

SD 72-SA-0054-3
JUNE 23, 1972

IN-SPACE PROPELLANT
LOGISTICS AND SAFETY

N72-30799



IN-SPACE PROPELLANT SYSTEMS SAFETY

Volume III

SYSTEM SAFETY ANALYSIS

Space Division
North American Rockwell

12214 Lakewood Boulevard, Downey, California 90241

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Volume III

SYSTEM SAFETY ANALYSIS

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North American Rockwell

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FOREWORD

This In-Space Propellant Logistics and Safety Study was performed by the Space Division of North American Rockwell Corporation for the National Aeronautics and Space Administration, Marshall Space Flight Center, under Contract NAS8-27692. The study was a twelve-month effort initiated on June 25, 1971, and completed on June 23, 1972.

The study was conducted as two separate, but related projects. One project addressed the systems and operational problems associated with the transport, transfer, and storage of cryogenic propellants in low earth orbits, while the other project addressed the safety problems connected with in-space propellant logistics operations. Correlation between the two projects was maintained by including safety considerations resulting from the System Safety Analysis in the trade studies and evaluations of alternate operating concepts in the Systems/Operations Analysis.

Walter E. Whitacre of Marshall Space Flight Center, Advanced Systems Analysis Office, was the Contracting Officer's Representative and provided technical direction to the overall contract and to the Systems/Operations Analysis project; Walter Stafford of the same office provided technical direction to the System Safety Analysis project. The contractor effort was under the direction of Robert E. Sexton, Program Manager; the Systems/Operations Analysis effort was led by Robert L. Moore and the System Safety Analysis effort was led by William E. Plaisted. Key technical contributors were G. F. Ruff, System Safety Analysis and Trade Studies, and J. R. Cook, Literature Review, Preventive Measures, and Guidelines and Requirements.

This document is Volume III of the following three volumes which contain the results of the System Safety Analysis:

Volume I	Executive Summary	(SD72-SA-0054-1)
Volume II	System Safety Guidelines and Requirements	(SD72-SA-0054-2)
Volume III	System Safety Analysis	(SD72-SA-0054-3)

The results of the Systems/Operations Analysis portion of the study are contained in the following five volumes:

Volume I	Executive Summary	(SD72-SA-0053-1)
Volume II	Technical Report	(SD72-SA-0053-2)
Volume III	Trade Studies	(SD72-SA-0053-3)
Volume IV	Project Planning Data	(SD72-SA-0053-4)
Volume V	Cost Estimates	(SD72-SA-0053-5)

This volume contains the System Safety Analysis of operations wherein propellants are 1) transported into space for subsequent use by another vehicle, 2) stored in space for later use, and/or 3) transferred from one element to another in space. Representative orbital logistic operations are developed, hazards are identified, and preventive measures are described which reduce catastrophic and critical hazards to marginal or negligible. Hazards not reduced to this level are identified as residuals. Safety evaluation trade studies of propellant transfer concepts are included.

CONTENTS

CONTENTS (Continued)

CONTENTS (CONTINUED)

CONTENTS (CONTINUED)

ILLUSTRATIONS

TABLES

TABLES (Continued)

1.0 INTRODUCTION

1.1 BACKGROUND

The National Aeronautics and Space Administration space program plan (1975-1995) encompasses a multitude of elements including space-based vehicles for transporting payloads from low earth orbit to geosynchronous, lunar and planetary orbit. These space-based vehicles require large quantities of propellants (primarily liquid oxygen and liquid hydrogen) and an in-space propellant logistics element to provide earth-to-earth orbit transport, earth orbital storage and in-space transfer of these propellants. Many of the routine operations required of the propellant logistic system are as yet undeveloped and are potentially hazardous. A vital step in the successful execution of the space program plan is the conduct of a system safety analysis of the propellant logistic operations. This has been accomplished and is reported in this document.

1.2 STUDY OBJECTIVES

The primary objective of the study was to examine from a system safety viewpoint the in-space propellant logistic elements and operations to define the potential hazards and to recommend means to reduce, eliminate or control them.

A secondary objective was to conduct trade studies of specific systems or operations to determine the safest of alternate approaches.

1.3 STUDY SCOPE AND REPORT ORGANIZATION

The study includes the safety evaluation of operations wherein propellants are 1) transported into space for subsequent use by another vehicle, 2) stored in space for later use, and or 3) transferred from one element to another in space. The evaluation encompasses potential elements which have received serious consideration by NASA in the time period 1975-1995. This broad scope has resulted in a very large amount of data which are usable and useful to those who will ultimately be charged with the design, development or operation of future space elements. Certain of these detailed data will be of interest to some, other data will be useful to others. All of the data will be of interest to System Safety Engineers.

An explanation of the organization of this volume is presented to assist in the best utilization of the data accumulated during the study.

Figure 1.3-1 is a schematic representation of the flow of data throughout the study and indicates the points at which the data accumulates in this volume.

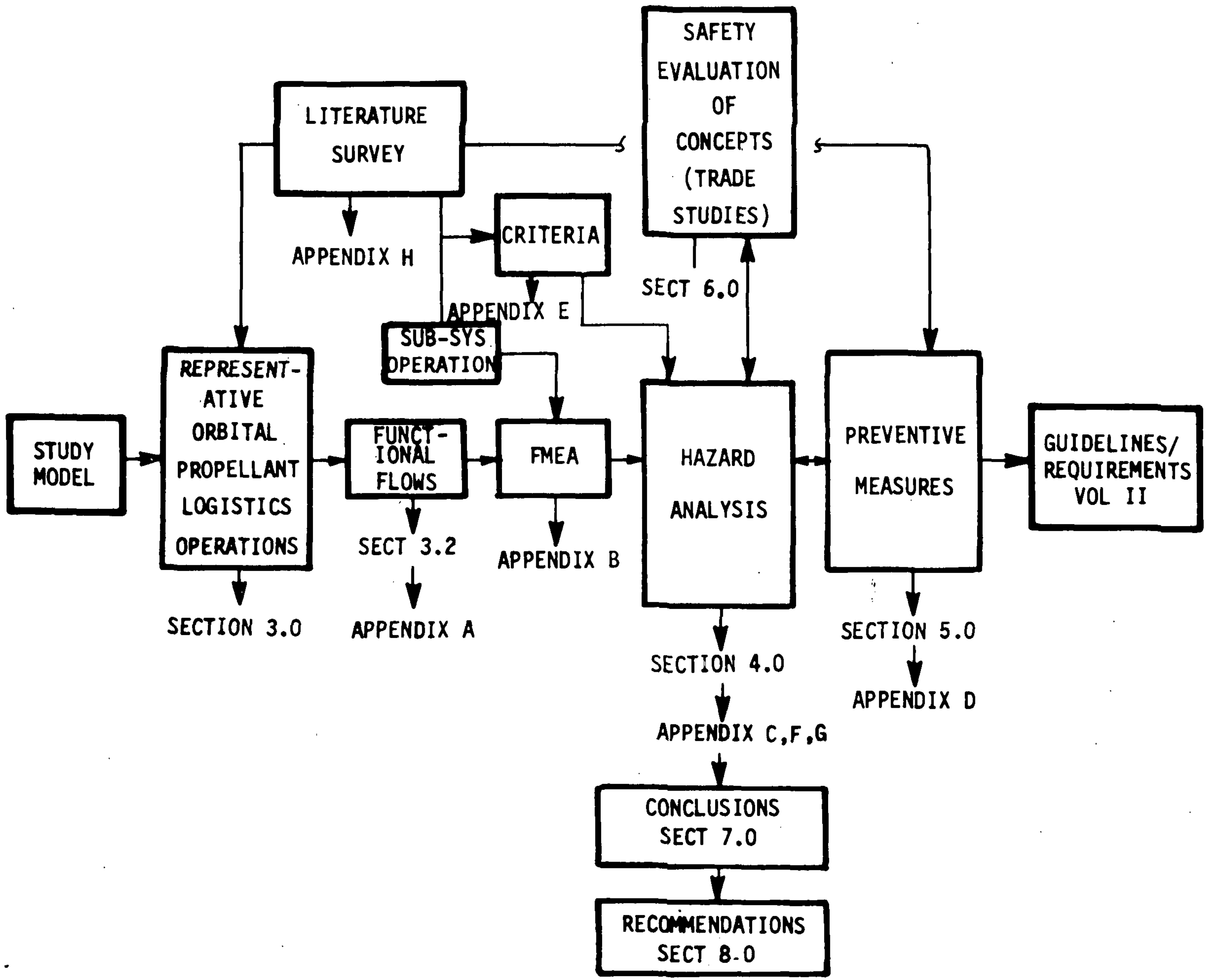


Figure 1.3-1 DATA FLOW FOR ISPLS SAFETY STUDY

This document is structured to preserve all the data and yet provide for rapid review of the entire scope by presenting the results in four levels of depth, each level providing increasing detail and reinforcing the previous level.

The first level provides the reader an overview of the entire study in Section 2.0 Study Approach and Summary.

The second level provides a summary of the technical discussion at the beginning of each of the following sections:

Section 3.0	Representative Orbital Logistics Operations
Section 4.0	Hazard Analysis
Section 5.0	Preventive Measures
Section 6.0	Trade Studies

The third level provides the technical discussion for each of these sections.

The fourth level of information presents the following appendices of data in support of the detailed study activities.

Appendix A	Representative Orbital Propellant Logistics Operations and Functional Flow Diagrams
Appendix B	FMEA's
Appendix C	Hazard Analysis Sheets
Appendix D	Preventive Measures
Appendix E	Safety Criteria
Appendix F	Conditions Contributing to Hazards
Appendix G	Safety Evaluation of Slush Hydrogen
Appendix H	Literature Review Reference
Appendix I	List of Abbreviations and Definitions

2.0 STUDY APPROACH AND SUMMARY

2.1 STUDY APPROACH

A space program model for the system safety analysis of the in-space propellant logistic operations was established. It was the intent to establish a model which involved all conceivably credible propellant logistic operations. The space program elements, Figure 2.1-1, considered were:

Space-Based Propellant User Vehicles

- Tug
- CIS/RNS
- Modular User (special case)
- Shuttle Orbiter (special case)

Earth-to-Earth Orbit Transport Modes

- Shuttle Orbiter Cargo Bay
- Shuttle Booster with Expendable Second Stage (ESS)

Propellant Elements

- Propellant Logistic Module for Shuttle Cargo Bay
- Large Propellant Logistic Tank for ESS Delivery
- Large Orbital Storage Facility (LSF)

The study baseline, Figure 2.1-2, consisted of a large earth orbital storage facility (LSF) which was re-supplied from a propellant module (PM) carried in the shuttle cargo bay; the space-based tug and CIS/RNS user vehicles; and fluid flow propellant transfer utilizing rotational acceleration for settling of the propellants during the transfer operation, both from the propellant logistics module to the LSF and from the LSF to the user vehicles. The initial assembly of the LSF is included in the baseline. The baseline model included two alternative earth-to-earth orbit propellant transport techniques which expanded the operations for analysis somewhat:

1) Delivery of the PM in the shuttle cargo bay to one orbital altitude and transfer of the PM to the LSF at a higher altitude using the space-based tug.

2) Delivery of a large quantity of propellants directly to the CIS/RNS using the shuttle booster with an expendable second stage as the transport mode.

Functional flows depicting the operation of the baseline were developed and from these the propellant logistic/transfer related operations were isolated. The propellant operations were evaluated in detail to establish hardware and procedural failure modes and effects and documented on FMEA

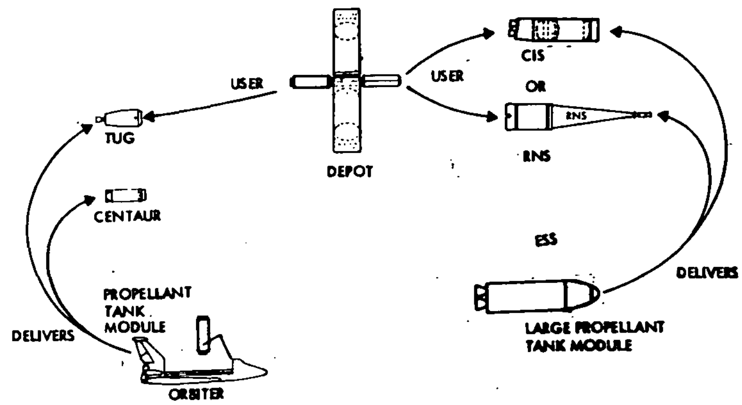


Figure 2.1-1 Propellant Logistics Elements

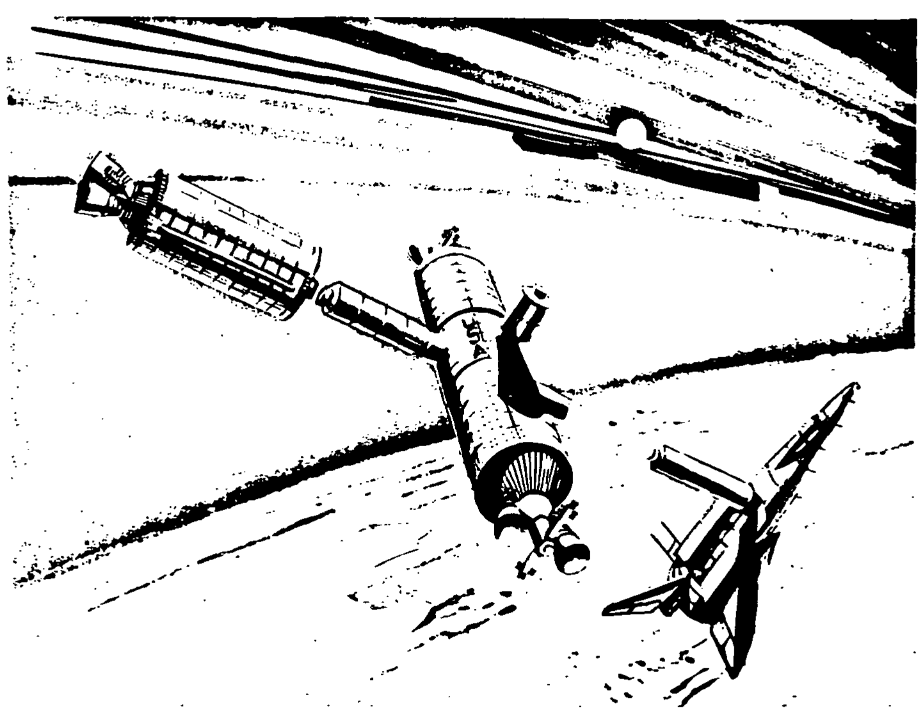


Figure 2.1-2 Propellant Logistics Concept with Storage

forms. From that evaluation the propellant related hazards were identified and each of these were analyzed in detail and documented on Hazard Analysis forms. Unique ground operations were included in this analysis. For each hazard, preventive measures were recommended on the same form.

Careful review and correlation of the baseline model analysis results provided these significant observations:

1. The critical operations were represented by seven categories of representative orbital operations as shown by the top three rows of Table 2.1-1.

2. The hazards fell into fifteen basic categories for deployment, docking, transfer and retrieval in propellant logistics operations. These are shown in Table 2.1-2.

Examination of the space program plan led to the following additional operations not included in the baseline model as representative:

1. Orbiter to orbiter introduces the use of flex lines and positive expulsion for propellant transfer.

2. Orbiter to tug brings out the use of rotational mechanisms for deployment, and rotational and linear acceleration with a manned vehicle (orbiter) attached.

3. Orbiter to CIS/RNS, Figure 2.1-3, employs the additional operation of the orbiter hard docking a propellant module to a large, partially full vehicle, the linear acceleration of a large CIS/RNS and propellant tank module and capillary fluid control.

4. Orbiter to modular user adds the operation of a module being deployed by both rotational and manipulator mechanisms.

The inclusion of these on Table 2.1-1 brings the total number of representative propellant logistics operations to 16.

In the application of Preventive Measures, the Hazard Reduction Procedure Sequence of SPD1-A was followed. The steps taken were in this order:

1) Design the hazard out
2) or, Use Safety Devices
3) or, Use Warning Devices
4) or, Develop Special Procedures

The only hazards addressed in the preventive measures analysis were those initially classed as catastrophic and critical. If, in the application of preventive measures, the hazard was not reduced to below the level of critical, the hazard was a residual one. Thirty-three residual hazards were so identified. The predominant residual hazards are those dealing with overall vehicle dynamics, EVA operations, propellants venting into cargo bay, and excess landing weight.

Table 2.1-1 In-Space Propellant Logistics Safety Critical Operations

CONCEPT \ OPERATIONS	1 DEPLOYMENT	2 DOCKING	3 TRANSFER	4 RETRIEVAL
A BASELINE	PROPELLANT TANK MODULE DEPLOYED BY MANIPULATORS FROM CARGO BAY	SHUTTLE SOFT DOCKS PROPELLANT TANK MODULE TO LSF REMOTE HARD DOCK CIS TO LSF	ROTATIONAL ACCELERATION OF LSF FOR PROPELLANT SETTLING - CIS/RNS - ORBITER UNATTACHED	PROPELLANT TANK RETRIEVAL--EMPLACEMENT IN CARGO BAY & DEORBIT OF ORBITER
B ORBITER/TUG/LSF		REMOTE HARD DOCK TUG/MODULE TO LSF		
C BOOSTER/ESS/LARGE PROPELLANT TANK		REMOTE HARD DOCK OF LARGE PROPEL-LANT TANK WITH CIS/RNS		
D ORBITER TO ORBITER			FLEX LINES USED BY ATTACHING AT QD WITH USE OF MANIPULATORS POSITIVE DISPLACEMENT METHOD USED FOR PRO-PELLANT TRANSFER	
E ORBITER TO TUG	PROPELLANT TANK MODULE DEPLOYED BY ROTATIONAL DEPLOYMENT MECHANISM		ROTATIONAL OR LINEAR ACCELERATION FOR PROPELLANT SETTLING WITH ORBITER ATTACHED	
F ORBITER TO CIS/RNS		ORBITER HARD DOCKS PROPELLANT TANK MODULE TO CIS/RNS	LINEAR ACCELERATION FOR CIS/RNS/TANK MODULE PRO-PELLANT SETTLING WITH ORBITER NOT ATTACHED CAPILLARY FLUID CONTROL FOR CIS/RNS/TANK MODULE PROPELLANT TRANSFER	
G ORBITER TO MODULAR CIS	PROPELLANT TANK MODULE DEPLOYED BY ROTATIONAL & MANIPULATOR MECHANISMS			

Table 2.1-2 Propellant Logistic Operations Hazards

HAZARD GROUP	DEPLOYMENT	DOCKING	TRANSFER	RETRIEVAL
1. FIRE/EXPLOSION/IMPLOSION	X	X	X	X
2. REDUCED INTEGRITY OF STRUCTURE OR EQUIPMENT				
2-1 LOSS OF PRESSURIZATION CONTROL			X	X
2-2 THERMAL SHOCK	X		X	X
2-3 FAILURE OF LINE INTERCONNECT FIXTURE	X		X	X
2-4 LEAKAGE OR MASS SPILL	X	X	X	X
2-5 LOSS OF LIQUID VAPOR INTERFACE CONTROL			X	
2-6 DEGRADATION OF MANNED ELEMENTS			X	X
3. CONTAMINATION	X	X	X	X
8. IMPACT	X	X	X	X
9. LOSS OF ATTITUDE CONTROL	X	X	X	X
11. LOSS OF COMMUNICATIONS			X	
12. DISTURBANCES				
12-1 SLOSHING	X	X	X	X
12-2 DYNAMIC COUPLING	X	X	X	X
12-3 LOSS OF CG CONTROL		X	X	
12-4 UNCONTROLLED VENTING	X	X	X	X

Figure 2.1-3 PROPELLANT LOGISTICS CONCEPT WITHOUT STORAGE

One of the objectives of the System Safety Analysis was to conduct trade studies of candidate systems concepts and modes in order to recommend the safest among competing options. In each of several subjects the methods and criteria used for evaluation are presented. The subjects studied are:

1) Safety Evaluation of Manipulator and Rotational Deployment Mechanisms

2) Safety Evaluation of Orbiter Attached and Orbiter Not Attached for Propellant Transfer

3) Safety Comparison of Four Tug Propellant Transfer Concepts

4) Safety Comparison of Four CIS/RNS Transfer Concepts

5) Safety Evaluation of a Modular Concept - CIS/RNS Type

6) Safety Evaluation of Orbiter-to-Orbiter Transfer

Additional details of the options considered, the manner in which they are used, and the criteria used to make the evaluation are contained in Section 6.0 of this report.

2.2 SUMMARY

The sixteen Representative Orbital Logistics Operations involving deployment, docking, transfer and retrieval (see Table 2.1-1) were investigated for a combination of fifteen hazard groups and subgroups (see Table 2.1-2) and conditions contributing to these hazards were identified in Section 4.0, Hazard Analysis.

As the Hazard Analysis progressed, it became evident that a greater level of analysis was required for several critical areas. The first of these critical areas involves the shuttle orbiter and the hazards associated with propellant logistic elements in the cargo bay. These include:

The unique prelaunch cargo bay operations involving loading of slush or liquid hydrogen into the propellant logistic element in the cargo bay.

The orbital cargo bay operations involving deployment of elements out of the bay, docking, transfer and retrieval.

Another critical area involves the effect of propulsive venting on element's control during propellant logistic operations.

The last critical area investigated involved the abort considerations.

Analysis of the prelaunch cargo bay operations disclosed the requirement for the sequential loading of propellants (LOX first, then LH_2), the need for the provision of propellant off-load capability and propellant dump capability. Loading of slush hydrogen can be achieved by pumping the slush through highly insulated facility lines directly into the propellant tanks

of the logistic element in the cargo bay. The module can also be filled at the slush facility and then transferred to the cargo bay. Heat input into the lines can produce liquification of the slush which can lead to slug flow. The operation of transporting a module loaded with slush to the cargo bay is especially hazardous because remote handling is not practical. Problems with the insulation could initiate a potential fire/explosion condition.

The hazards associated with orbital cargo bay operations involve collisions or vehicle instability from loss of control and sloshing. The deorbit phase of cargo bay operations and the preparation to the propellant module for re-entry are critical to the safety of the orbiter and crew. An evaluation of hydrogen leakage into the cargo bay shows the propellant elements can be safely deorbited in the cargo bay if the necessary precautions are taken. These precautions would include the examination of propellant consumption records and a visual inspection of the module for leakage prior to emplacement in the cargo bay. A visual inspection should also be made of the cargo bay walls. When the module is placed in the cargo bay it should be securely attached to its mounting points and vent/dump interface. The vent/dump connection should next be leak checked to determine connection integrity.

The next step would be to dump the residual liquids from the propellant tanks and to make a gross leak check of the entire hydrogen system. If no leakage exceeding specification requirements was evident from these tests, the module can safely be deorbited because normal (within specifications) leakage is not hazardous. If out of specification leakage is evident, then the module should be left in orbit until corrective action can be taken.

Out of specification leakage in the cargo bay can lead to a buildup of solidified hydrogen on the walls of the bay. Under deorbit conditions the mixture of this hydrogen with the oxygen in the atmosphere and the potential ignition sources make fire/explosion a credible hazard. An investigation of the time necessary to sublime the solidified propellants determined that with the orbiter cargo bay orientated to allow maximum solar heating, a worst case credible spill could be removed from the bay in two hours.

Abort, under worst case time conditions, will require the dump of a maximum of 25K lb. of propellants in 200 seconds to meet the 40K lb. landing requirement of the orbiter.

An integral part of System Safety analysis is the development of preventive measures to reduce hazard potential. As a part of the hazard analysis process the hazard was identified and the conditions that caused the hazard to exist or occur were enumerated. It follows, then, that if the conditions that led to the hazard were corrected by preventive measures the hazard would not occur.

In the application of Preventive Measures the Hazard Reduction Precedence Sequence of SPD1-A was followed. The steps taken were in this order:

a. Design the hazard out
b. or, Use Safety Devices
c. or, Use Warning Devices
d. or, Develop Special Procedures.

The only hazards considered in the analysis were those classed as catastrophic and critical. If, in the application of preventive measures, the hazard was not reduced to below the level of critical the hazard was classed a residual one. Thirty-three residual hazards were so identified.

Among the residual hazards are those dealing with overall vehicle dynamics, EVA operations, propellants venting into cargo bay, excess landing weight and others that are listed in Section 5.0 and Appendix F.

One of the objectives of the System Safety Analysis was to conduct trade studies of candidate systems, concepts and modes in order to recommend the safest among competing options. In each of several subjects the methods and criteria used for evaluation are presented. The subjects studied and the result of the trades are:

a. Safety Evaluation of Manipulator versus Rotational Deployment Mechanisms - The trade established no clear-cut advantage in using either type of mechanism.

b. Safety Evaluation of Orbiter Attached versus Orbiter Not Attached for Propellant Transfer - It was concluded that there were greater requirements for safety with the orbiter attached.

c. Safety Comparison of Four Tug Propellant Transfer Concepts - The concept of leaving the tank in the cargo bay and docking to the side of the tank was the preferred approach.

d. Safety Comparison of Four CIS/RNS Transfer Concepts - The preferred propellant transfer mode was with the CIS/RNS and module attached and linearly accelerated for transfer.

e. Safety Evaluation of a Modular Concept, CIS/RNS Type - The safety evaluation of such a concept indicates it to be competitive with the non-modular approach.

f. Safety Evaluation of Orbiter-to-Orbiter Transfer - Of the three approaches investigated, no safety preference could be defined. As the configuration reaches maturity additional trades should be conducted.

Additional details of the options considered, the manner in which they are used, and the criteria used to make the evaluation are contained in Section 6.0.

Section 7.0 of Volume III contains the conclusions that were reached by performing the System Safety Analysis of propellant logistics operations. Among these conclusions are:

a. Propellant delivery direct to a user without storage is a safer concept than with storage because of the reduction of the complexity of the operations.

b. Deployment of a propellant logistics element from the cargo bay should be accomplished with a combination of the manipulator and rotational deployment mechanisms.

c. Modular transfer of propellants to a modular user is a recommended concept.

d. The effect of disturbances on vehicle control systems during propellant logistics operations is a residual hazard.

Other conclusions are contained in Section 7.0.

Volume III concludes with recommendations for additional study.

a. Through the loss or degradation of insulation the tank walls of a module can develop hot spots. Upon re-entry residual propellants could contact these hot spots and flash into vapor. This sudden increase in pressure could exceed the capability of the vent system and lead to tank over-pressures or rupture. The capability of the chosen systems to overcome this hazard should be resolved.

b. The overall dynamics of the propellant logistics system should be studied to determine the effects of sloshing, vehicle compliance, coupling and other forces on the ability to maintain vehicle stability.

3.0 REPRESENTATIVE ORBITAL PROPELLANT LOGISTIC OPERATIONS

This section covers the development of representative orbital propellant logistics operations from which hazards were identified for analysis. Propellant logistic elements and missions that were viable options were considered, resulting in selection of a baseline concept. The baseline concept consists of an orbiter delivering a propellant tank module to a Large Storage Facility (LSF) from which orbital user elements such as CIS/RNS and tug were supplied propellants. Rotational acceleration was the mode used for propellant settling during transfer operations.

Variations to the baseline, which added critical operations not contained in the baseline, were (1) the tug added to the delivery mode in the baseline, (2) Booster/ESS/large propellant tank as a delivery element to CIS/RNS, and (3) the orbiter delivery of propellants direct to users, such as an orbiter, tug, CIS/RNS or modular element.

Major critical on-orbit operations of deployment, docking, transfer, and retrieval, and unique ground operations involving handling of slush hydrogen and filling logistics elements in the cargo bay, were evaluated.

Critical operations of deployment considered the use of rotational and manipulator deployment mechanisms singly and in combination. Docking considered both soft and hard docking concepts with configurations loading both small and large quantities of propellants. This involved such cases as:

1. Orbiter manipulators soft dock a propellant tank module to a large storage facility with varying quantities of propellants.

2. Empty CIS/RNS hard docks to a large storage facility with varying quantities of propellants.

3. Tug with full propellant tank module hard docks to large storage facility with varying quantities of propellants.

4. ESS/large propellant tank hard docks to large empty CIS.

5. Orbiter hard docks a propellant tank module to a CIS/RNS with varying quantities of propellants in tanks.

Critical transfer operations considered rotational and linear acceleration for propellant settling and use of capillary or positive expulsion devices. These involve such cases as:

1. Rotation with propellant tank, LSF and CIS/RNS

2. Rotation with orbiter/propellant tank/tug

3. Rotation with orbiter/propellant tank and CIS/RNS

4. Linear with orbiter/propellant tank/tug

5. Linear with propellant tank/CIS or RNS

6. Capillary with propellant tank/CIS or RNS

7. Propellant tank transfer to a modular element (CIS type)

8. Positive displacement through flex lines - orbiter to orbiter

Critical operations of retrieval considered use of manipulators and direct hard docking for retrieval of empty propellant tank modules, and those operations of stowing the module in the orbiter cargo bay and deorbit. This involves such cases as:

1. Manipulator emplacement of propellant tank module into the orbiter cargo bay and making necessary system hookup connections.

2. Orbiter hard dock to propellant tank module on CIS using rotational deployment mechanism and subsequent undocking at the CIS interface with emplacement of the tank into the cargo bay.

3. For the modular element, the empty tank module is retrieved by manipulator, docked to the rotational deployment mechanism and rotated into the cargo bay.

Selection of these representative orbital propellant logistic operations provided the study with conditions containing the majority of hazards which could be expected in any propellant logistic concept.

3.1 REPRESENTATIVE CONCEPTS

The development of the representative orbital propellant logistics operations considered the propellant logistics elements and missions that were viable options in the space program. The baseline concept chosen for determining the critical operations during deployment, docking, transfer and retrieval was the orbiter delivering propellants to a large storage facility (LSF) in earth orbit from which other orbital elements such as CIS, RNS and tug were supplied propellants.

Variations to the baseline concept, which added operations not contained in the baseline, involved the tug and ESS as delivery elements and the orbiter direct to users including a modular element.

Functional flow diagrams were prepared for the baseline concept and added tug delivery concept and the booster/ESS delivery concept for use in hazard analysis.

3.2 FUNCTIONAL FLOW DIAGRAMS

The operation of the conceptual representative orbital propellant logistic system baseline is depicted in Figure 3.2-1, for the orbiter to LSF. As the baseline is adjusted for sharing delivery of the propellant tank module with the tug, the delta to the system is depicted in Figure 3.2-2.

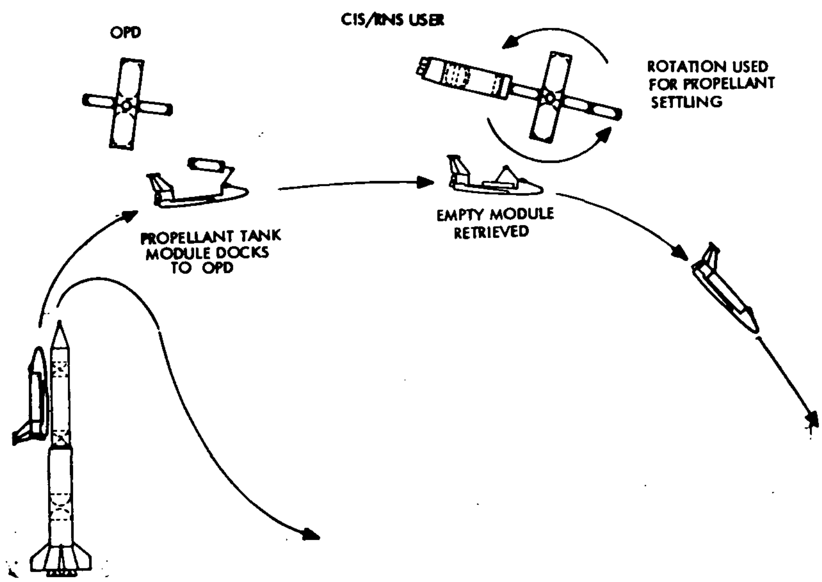


Figure 3.2-1 Baseline Orbiter/OPD/User Mission Profile

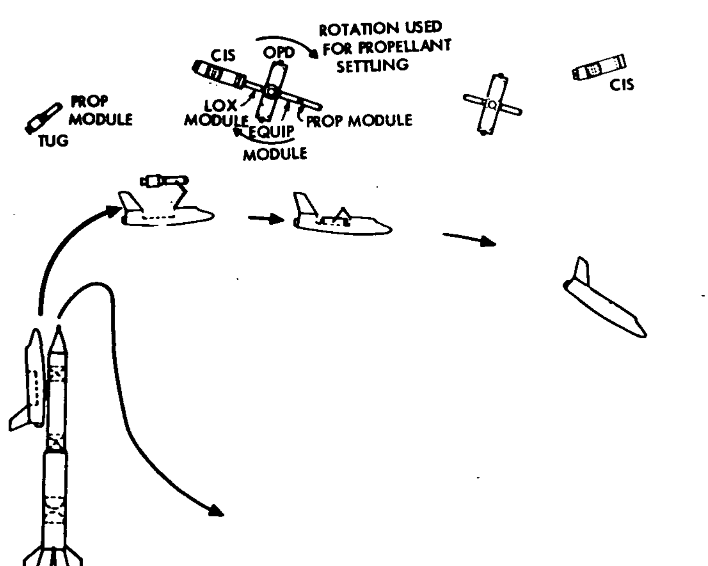


Figure 3.2-2 Orbiter/Tug/Large Storage Facility

3.2.1 Orbital Propellant Logistic Functions

The representative orbital propellant logistic functions will be compatible with the top-level functional flow diagrams (FFD's) (see Figures 3.2.1-1 for baseline and 3.2.1-2 for tug variation) listed below and all applicable subfunctions:

1.0 Perform Installation Checkout Operations
2.0 Perform Assembly and Launch to Orbit
3.0 Perform Orbital Buildup Operations
*3.0A Transfer Mission Payload Delivery Function (Tug)
4.0 Perform Propellant Transfer Operations
*4.0A Perform Propellant Transfer Operations (Tug)
5.0 Perform Maintenance Operations
6.0 Undock, Stow and Deorbit/Land
7.0 Perform Mission Abort Operations
8.0 Perform Emergency Rescue Operations
9.0 Deactivate Propellant Logistics Element

*Baseline variation (shuttle/tug delivery) denoted by the letter A.

The following paragraphs specify the activities and events for each top-level FFD associated with the operational phase. Functional flow diagram 2.0 addressed the unique operation of slush hydrogen and cargo bay loading operations. Functional flow diagrams 4.0 and 6.0 were given maximum study emphasis because of the orbital operations involved. Abort considerations were identified in FFD 7.0.

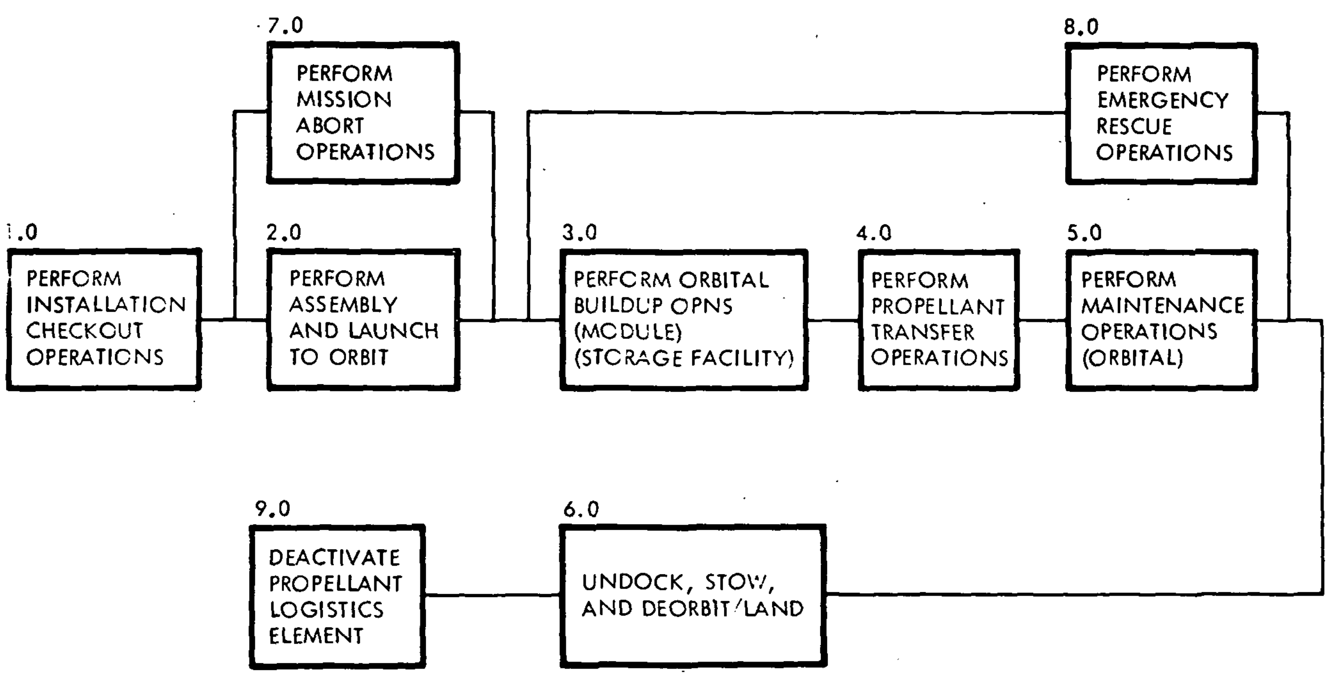


Figure 3.2.1-1 Top Level Functional Flow Propellant Logistics System Elements (Shuttle Alone)

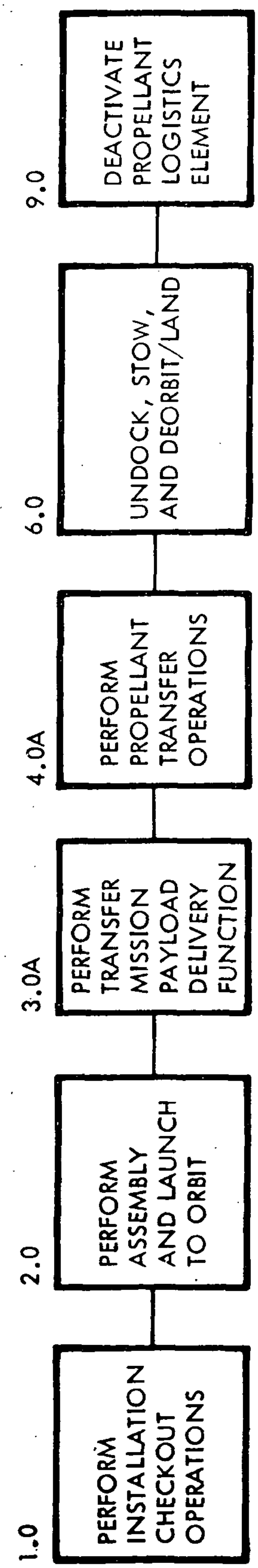


Figure 3.2.1-2 Top Level Functional Flow Propellant Logistic System Elements (Shuttle/Tug)

Perform Assembly and Launch to Orbit (2.0). This function includes premate checkout, payload integration, vehicle mating, transport, erection, propellant loading, crew and passenger loading, final servicing, checkout, launch countdown ignition, release, launch, boost, staging, and orbiter arrival at mission orbit.

Perform Orbital Buildup Operations (3.0). This function covers all activities associated with the buildup of the Large Storage Facility (LSF) including rendezvous, equipment and support module emplacement, deployment and docking of involved modules and personnel, activation and checkout of subsystems, undocking, separation and standoff.

Perform Transfer of Mission Payload Delivery Function (3.0A). This function covers the initial space based vehicle deployment from the orbiter, propellant transfer thereto, alternative deployment of payload propulsive stage and payload, separation from the delivery vehicle, alternative deployment of propellant module, down modules and down delivery vehicles transfer to the orbiter cargo bay, docking of propellant module to tug and separation therefrom.

Perform Propellant Transfer Operation (4.0). This function for the orbiter functioning alone covers orbit and phase change, rendezvous, deployment, docking, transfer of propellant module, transfer of small propellant dewars, and retrieval of down propellant modules.

Perform Propellant Transfer Operation (4.0A). This function covers orbital operations of the space based vehicle including orbit and phase change, rendezvous with LSF, docking of propellant module, undocking, maneuvering, transfer of propellants, retrieval of empty modules, transfer orbit insertion, and rendezvous with the orbiter.

Perform Maintenance Operations (5.0). This function covers the orbiter operation for performing maintenance and includes orbit and phase change, rendezvous, docking, offloading of maintenance crew, undocking, separation, station-keeping, re-docking, transfer of down modules and on-loading of maintenance crew and cargo.

Undock, Stow and Deorbit/Land (6.0). This function covers undocking, enplacement of module into cargo bay, securing module, configuring orbiter for deorbit, retro maneuver, re-entry, atmospheric flight subsystems checkout and configuring, approach and landing.

Perform Mission Abort Operations (7.0). This function covers booster and orbiter pad and mated ascent abort operations, booster post separation abort, orbiter ascent abort, orbiter landing abort, and orbiter abort from orbit.

Perform Rescue Mission (8.0). This function includes performance of orbit and phase changes, rendezvous with distressed space element, docking, attaching and loading rescued passengers and minor cargo.

Deactivate Propellant Logistics Element (9.0). This function begins with transport to the safing area and includes post flight safing, crew and passenger egress, cargo unloading, transport to the maintenance hangar, inspection, post flight checkout and data processing, maintenance, repair, refurbishment, post-maintenance checkout, storage or delivery to the premate checkout area. With this set of functional flow block diagrams we have established the functions of the logistic operations for delivery of propellants to a large storage facility.

3.3 OPERATIONS - CONCEPTS FOR PROPELLANT LOGISTICS WITH STORAGE

The following information describes the representative orbital logistics operations which support the use of the large storage facility. The shuttle booster is not included in these operations. See Appendix A for detailed operations.

Ground and pad operations as well as launch operations are essentially the same as for present propellant systems. The unique operations to be considered involve the handling of slush and the loading/off loading of the elements within the cargo bay of the orbiter.

The propellant logistics elements are launched to orbit and are assembled as a large storage facility using a set of orbital buildup operations. The transport and docking of equipment, crew and LO_2 modules with an orbiter to the large storage facility is included in these operations.

After assembly and activation, propellant tank modules are delivered to the LSF by the orbiter or the orbiter/tug variation.

The orbiter propellant logistics operations include deployment of the propellant tank module from the cargo bay and soft docking the module to the LSF using manipulators.

The orbiter/tug alternate delivery mode logistics operations include deployment of the propellant tank module from the cargo bay, soft docking to a tug, and tug/propellant module remote hard docking to an LSF at the higher orbit.

The unmanned LSF is rotated to provide propellant settling for the transfer of propellants from the module to the facility.

The orbiter returns to the LSF, retrieves and secures the module in the cargo bay and deorbits to earth.

If the orbiter/tug variation is used, the tug acquires the module from the LSF and delivers it to the orbiter which is at a lower orbit. After emplacement of the module in the cargo bay, the orbiter deorbits to earth.

These delivery operations continue until the LSF is filled with propellants and is ready for refueling a user vehicle.

User vehicles, Chemical Interorbital Shuttle (CIS) or Reusable Nuclear Shuttle (RNS), are remotely hard docked to the LSF. The configuration is rotated until the users are refueled. After the rotation is terminated, the user undocks from the LSF and performs its designated mission.

Maintenance operations for the LSF include the operations involving the equipment and crew modules at the LSF.

Abort operations for the orbiter involve propellant dumping as a function of weight and time to assure a safe landing.

3.4 OPERATIONS - CONCEPTS FOR PROPELLANT LOGISTICS WITHOUT STORAGE

Concept variations for delivery of propellants direct to user are included in this study to complete the set of representative orbital logistics operations. These concepts are Booster/Expendable Second Stage/Propellant Tank delivery direct to CIS or RNS, and orbiter direct to orbiter, to tug, to CIS or RNS and to a modular user.

3.4.1 Booster/ESS/Large Propellant Tank/CIS/RNS, Figure 3.4.1-1

The Booster/ESS/Large Propellant Tank concept was investigated as a delta to the representative orbital propellant logistic operation baseline. The operations involving deployment, docking, transfer and return to earth (impact) were analyzed within the functions established by top level functional flow diagram presented in Figure 3.4.1-2. First level functional flow diagrams are contained in Appendix A. This delta was analyzed for the different hazards involving operations where two large tanks will be hard docked by remote operational control.

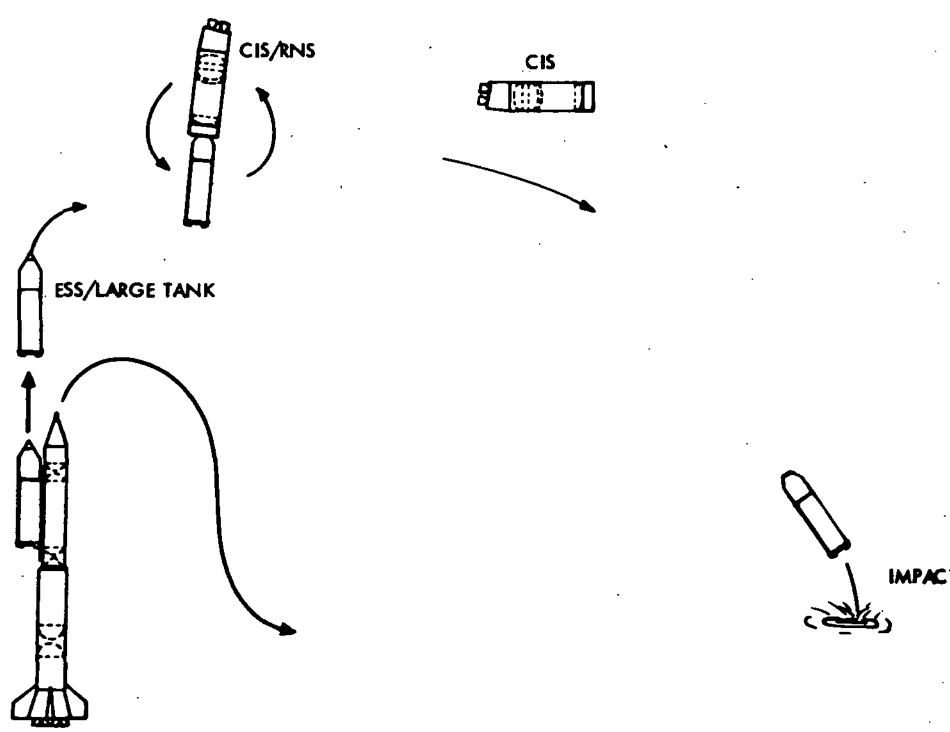


Figure 3.4.1-1 Booster/ESS/Large Propellant Tank/CIS/RNS

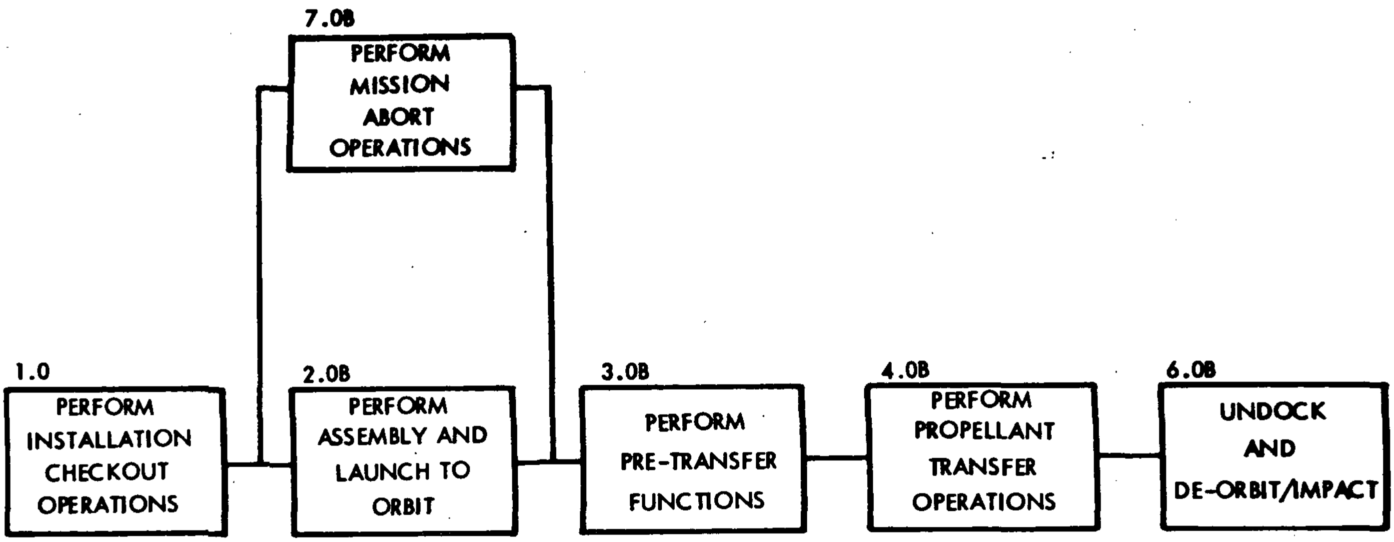


Figure 3.4.1-2 Booster/ESS/CIS/RNS

3.4.2 Orbiter to Orbiter Concept Variation, Figure 3.4.2-1

The critical operations of this variation are found in the transfer operations involving use of flex lines attached to a manipulator arm for connecting to the airborne half of the ground fill and drain quick disconnect. This variation also introduced for the first time the use of a positive displacement method for propellant transfer. Other operations of this concept had previously been analyzed in the baseline operations.

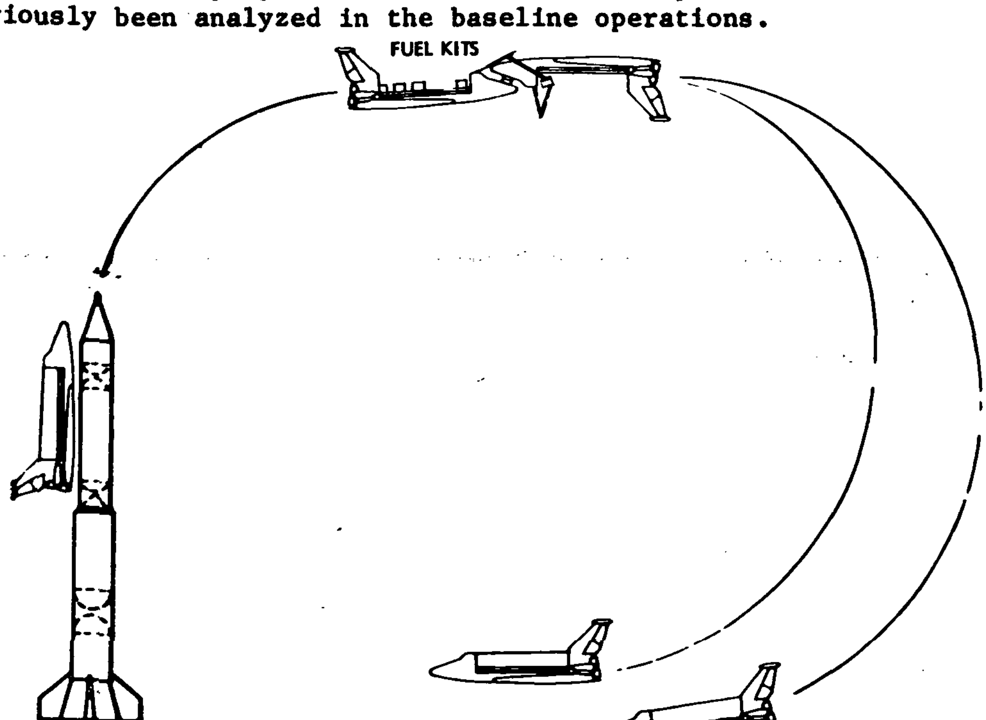


Figure 3.4.2-1 Orbiter Direct to Orbiter

3.4.3 Orbiter to Tug Concept Variation, Figure 3.4.3-1

This variation introduces critical deployment operations involving a propellant tank module deployed by a rotational deployment mechanism. Also the transfer operations introduced attachment of the orbiter to the tug for imparting a rotational or linear acceleration for propellant settling. These operations were again first introduced by this variation while other operations had been a part of the baseline concept.

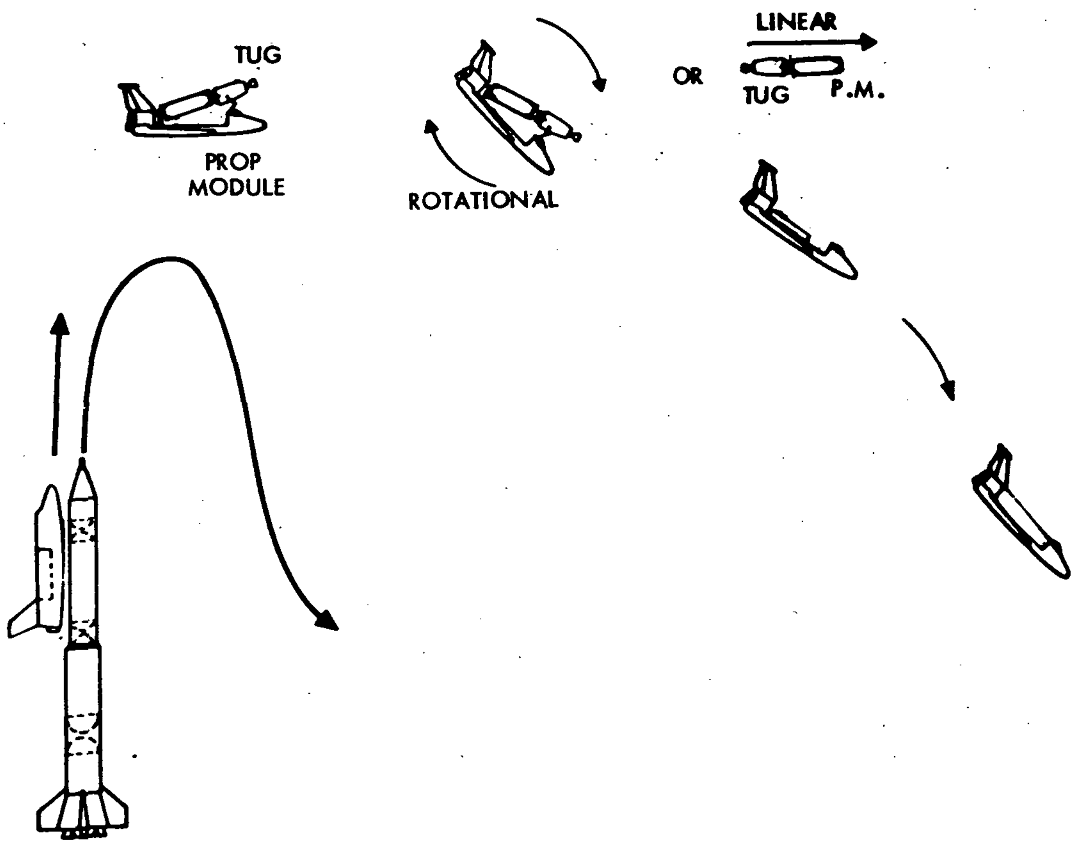


Figure 3.4.3-1 Orbiter to Tug Concept Variation

3.4.4 Orbiter to CIS/RNS Concept Variation, Figure 3.4.4-1

This concept variation introduced a new docking operation wherein the orbiter hard docks a propellant tank module to a large user; i.e., CIS/RNS. Other variations from the baseline in critical transfer operations involve linear acceleration for CIS/RNS/tank module propellant settling with the orbiter not attached and capillary fluid control for CIS/RNS/tank module propellant transfer. Other operations of this concept had been investigated in the baseline analysis.

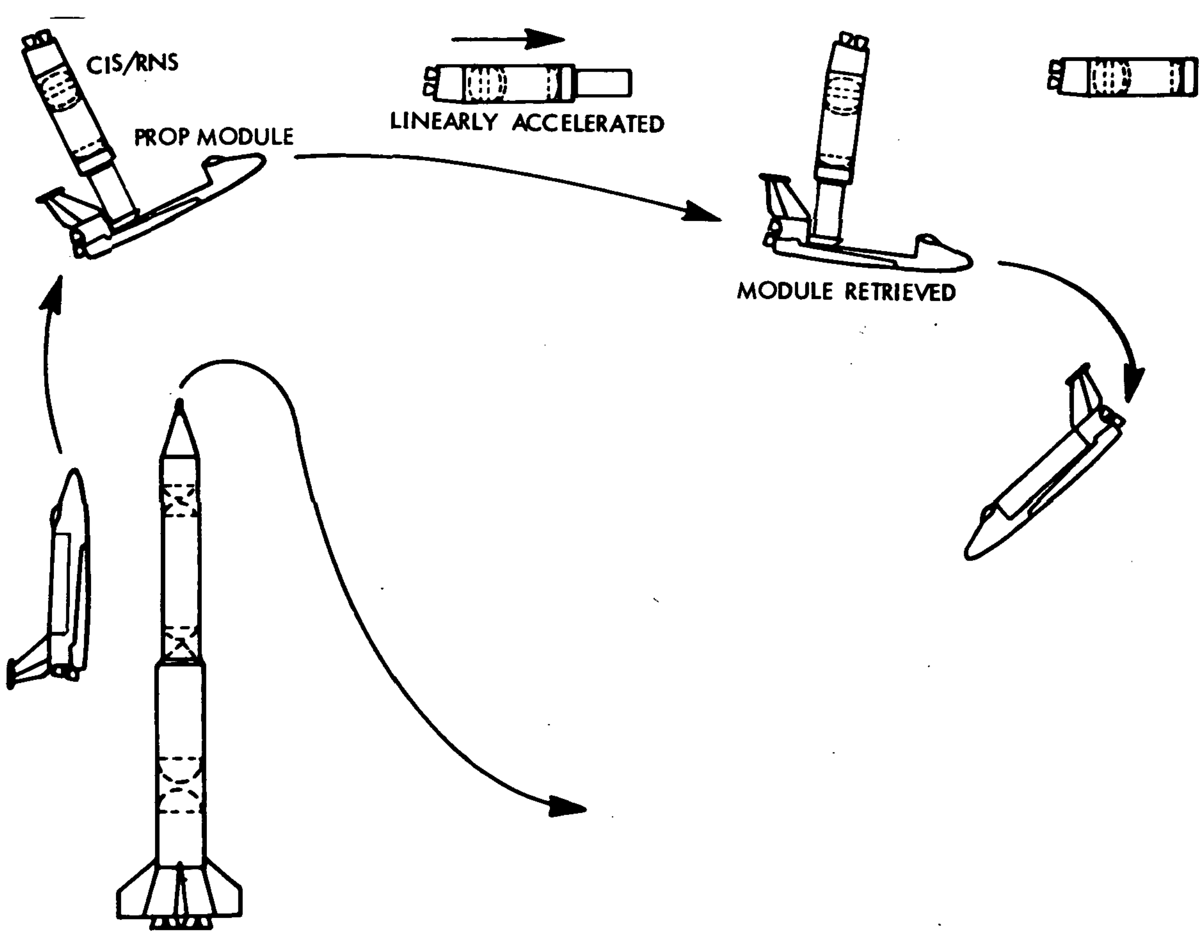


Figure 3.4.4-1 Orbiter Direct to CIS/RNS

3.4.5 Orbiter to Modular User Concept Variation, Figure 3.4.5-1

The operations of the baseline covered all but the variation in a critical deployment operation which involves the deployment of a propellant tank module in a coordinated action involving both rotational and manipulator deployment mechanisms. This concept introduced this critical deployment operational variation for analysis.

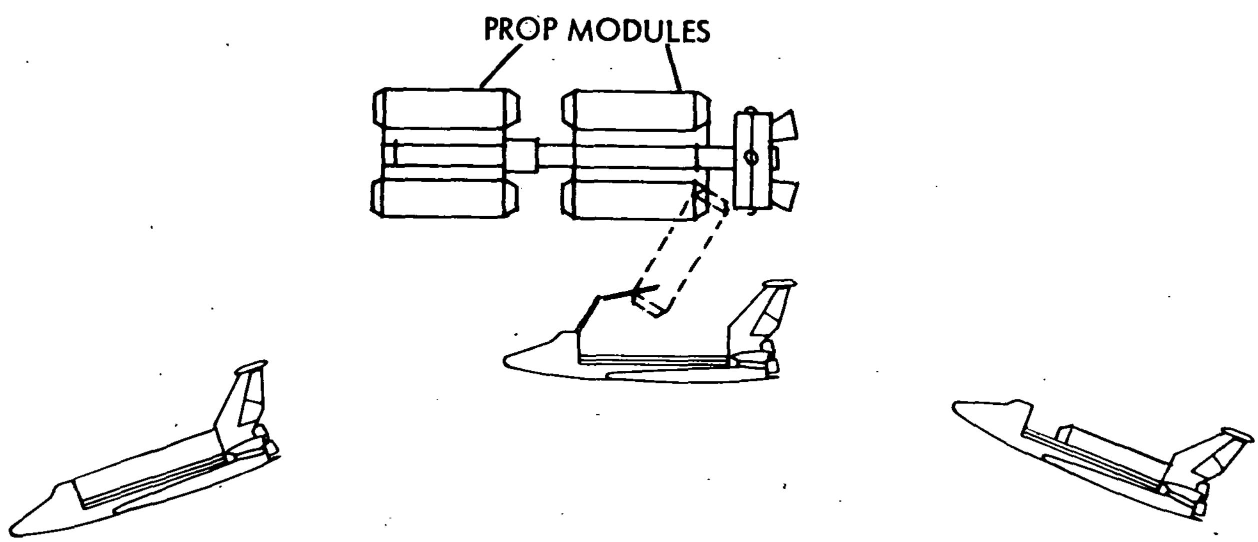


Figure 3.4.5-1 Propellant Transfer Option for Typical Modular Concept

The above operations of the baseline and baseline variations were the basis for the Hazard Analysis, discussed in the following section.

4.0 HAZARD ANALYSIS

This section covers those safety considerations and analyses needed to identify hazards associated with the functions, elements, operations, and interfaces of the baseline operations and variations to the baseline discussed in Section 3.0.

Conditions contributing to the hazards were identified and used in examination of operations involving the cargo bay area during all phases of the mission.

These examinations considered the loading of propellants into the tank modules while in the cargo bay, use of deployment mechanisms, docking using both soft and hard dock methods, and retrieval operations, which include return of the tank module to the cargo bay, stowing and deorbit preparation. Abort conditions were also examined. Propellants sloshing in zero G present the major condition for impact, leakage, and vehicle control hazards and are included in the above evaluations. For details of identified hazards see Hazard Analysis sheets in Appendix C.

Hazards associated with propellant logistic operations, as compared to hazards which were general to any orbital operation, were identified and arranged by hazard group for propellant logistic operations. See Table 4.0-1.

Conditions contributing to these hazards were developed for the basic operations. The conditions contributing to deployment hazards are generally associated with propellant tank module or logistic elements. Where the module is suspended on a manipulator, sloshing of propellants caused by RCS operation, undesired venting, or mass fluid spill causes impact and vehicle control hazards to prevail. The spills or uncontrolled venting in the cargo bay leads to hazards of thermal shock and contamination of TV lens and viewing ports by ice crystal formation. Fire and explosion could occur wherever the fluids are contained in concentrations of 4% H_2 - 2% O_2 at a pressure of 2 mm Hg or greater. Leaks occurring when the module is extended on the manipulator further cause attitude control problems.

Docking hazards are generally associated with sloshing, RCS action, or venting causing misalignment resulting in possible impact or damage. Failure to rigidize the docked configuration, while being restrained by a captive latch, causes potential rotation of the elements from the dynamic coupling of the elements, the RCS action and sloshing of the fluids. This hazard is most prevalent during hard docking when the orbiter is attached, and less prevalent where a soft dock is made with manipulators.

Transfer hazards are generally involved with dynamic control of the docked configurations. These hazards include CG excursion, dynamic coupling of the structure, fluid surface distortion and uncontrolled venting. Failures in the gas generators or heat exchangers could cause fire or explosion hazards.

Table 4.0-1 Propellant Logistic Operations Hazards

	HAZARD GROUP	DEPLOYMENT	DOCKING	TRANSFER	RETRIEVAL
1.	FIRE/EXPLOSION/IMPLOSION	X	X	X	X
2.	REDUCED INTEGRITY OF STRUCTURE OR EQUIPMENT				
	2-1 LOSS OF PRESSURIZATION CONTROL			X	X
	2-2 THERMAL SHOCK	X		X	X
	2-3 FAILURE OF LINE INTERCONNECT FIXTURE	X		X	X
	2-4 LEAKAGE OR MASS SPILL	X	X	X	X
	2-5 LOSS OF LIQUID VAPOR INTERFACE CONTROL			X	
	2-6 DEGRADATION OF MANNED ELEMENTS			X	X
3.	CONTAMINATION	X	X	X	X
8.	IMPACT	X	X	X	X
9.	LOSS OF ATTITUDE CONTROL	X	X	X	X
11.	LOSS OF COMMUNICATIONS			X	
12.	DISTURBANCES				
	12-1 SLOSHING	X	X	X	X
	12-2 DYNAMIC COUPLING	X	X	X	X
	12-3 LOSS OF CG CONTROL		X	X	
	12-4 UNCONTROLLED VENTING	X	X	X	X

Loss of the capability to despin, where the orbiter is attached, due to instability of the configuration is another type of hazard affecting the crew.

The predominant hazards associated with retrieval operations are related to leakage of hydrogen in the cargo bay during re-entry. Any module which cannot pass a leak check or contains excess residual propellants, which could be flashed off to exceed the tank relief capability, can cause fire/explosion during deorbit and re-entry. These conditions are emphased in later paragraphs.

An additional hazard closely related to the above is venting in the cargo bay during re-entry. However, properly designed and operating systems for re-connecting all vents prior to re-entry would minimize this problem.

An additional evaluation of cargo bay operations considered only unique ground operations such as loading of slush hydrogen into the propellant tank modules, the case of series or parallel loading facility systems for loading of LH_2-LO_2 into the tank modules, and emergency offload. Orbital operations involving the use of both rotational and manipulator deployment mechanisms for hard and soft docking, respectively, were evaluated. See Section 6.0 for detailed evaluation.

Retrieval operations were investigated which dealt with the hazards of attaching the module in the cargo bay such that line interconnect fixtures could be mated at the tank module interface with the cargo bay. Without proper indexing this can become a major problem; i.e., not capable of venting the tank in a closed system but rather divert to the cargo bay.

This venting or even possible leakage into the cargo bay would be in the form of ice crystals or snow which adheres to the cargo bay walls. It will sublime away over a period of hours with proper orbiter orientation for maximum heating.

Abort considerations are addressed in this section and are related to sub-orbital abort, centered around orbiter abort and operational modes. They relate specifically to off loading of the orbiter to 40K payload weight for safe landing. Greater payload landing weight can be accommodated however at a lesser factor of safety. The operational mode wherein 200 seconds is available for orbiter landing constrains the offload abort requirements.

The analysis identified hazards within the representative orbital propellant logistic operations which have an influence on the design of Space Logistics Systems. These are:

1. Location and indexing of the line interconnect fixture mating interface (location of the module attach points with the cargo bay attach fitting) must be predetermined for each retrieved element.

2. The quantity of residual propellants, which if completely flashed off could overpressurize the tank module, must be accurately known to prevent an explosion.

3. All logistic elements in the cargo bay must be capable of gravity feed off loading under emergency conditions.

4. The effects of disturbances coupling with configuration dynamics must be addressed especially when the orbiter constitutes part of the configuration.

5. The hazard associated with dumping 25K lbs. of propellant in no more than 200 seconds must be considered from both dump line size and flame attenuation capability at the outlet.

4.1 ANALYSIS OF HAZARD DATA

4.1.1 Background

The concepts described in Section 3.0 were analyzed for hazards within the functions and space element operations or interfaces. See Appendix C for definition of hazards. The functions and operations or interfaces were subjected to FMEA development, which identified failures with hazard potential. The FMEA's are contained in Appendix B. Hazards within the baseline were identified, using the FMEA's and operations data. See Appendix C. Additional hazards were identified in the orbiter/tug/LSF concept variation and the booster/ESS/large propellant tank concept. FMEA's and Hazard Sheets were prepared for these variations. See Appendix B for FMEA's and Appendix C for Hazard Sheets. Failures and effects for the variations are contained in the Trade Studies and safety evaluations in Section 6.0. Specific attention was given to orbiter cargo bay operations in paragraph 4.2. Table 2.1-1 shows a summary of safety critical operations by concept and operational phase. Safety critical operations are defined as those operations involving systems, subsystems, or components of the space elements identified as having a hazard potential to personnel, associated equipment and the space elements.

4.1.2 Hazard Groups

Identified hazards have been arranged by hazard groups. These groupings are described in Appendix C.

The identified hazards covered unique ground operations, launch and ascent, orbital, deorbit, landing and safing operations. A filtering of the hazards involved in orbital operations of deployment, docking, transfer and retrieval was then made to identify those hazards which were related to propellant logistic operations alone as compared to hazards which were general to any orbital operation.

Fifteen hazards were identified and related to the critical operations of deployment, docking, transfer, and retrieval. See Table 4.0-1.

Conditions contributing to each hazard were identified and related to the safety critical operations. Rationale is given for each contributing condition by operation. These hazards are addressed in:

A listing of conditions contributing to propellant logistic hazards is contained in Appendix F.

4.2 ORBITER CARGO BAY OPERATIONS HAZARDS

The baseline delivery element for propellant logistic operations in space is the shuttle orbiter vehicle. The major interface between the space elements and orbiter is the cargo bay. It is therefore appropriate that those operations directly relating to, and involving the orbiter cargo bay area be emphasized. The discussion progresses through the phases of prelaunch, launch and ascent, orbital, deorbit and abort operations.

4.2.1 Prelaunch

Prelaunch operations for the propellant logistic element are generally similar to those for any large space element. In this phase of analysis consideration was given to the type of propellant fill system required to load a propellant tank module while in the orbiter cargo bay. An option for consideration was the use of slush hydrogen and attendant systems. The hazards associated with slush hydrogen operations were considered.

Table 4.1.2-1
CONDITIONS CONTRIBUTING TO FIRE AND EXPLOSION HAZARDS
(Hazard Group 1)

1. Deployment	
a. Tank Rupture - Causing fluids to mix, 4% H_2, 2% O_2 min. at 2 mm Hg or more pressure.	Dual leakage into any confined volume could raise pressure to 2 mm Hg and result in fire/explosion when ignited by shock, friction or catalytic action.
b. Line Rupture - Occurring when index probes did not release.	When index probes unlock but do not fully release, movement of the module could rupture both lines if on one fixture. Local pressure by impinging fluids could be high enough to lead to fire/explosion.
2. Docking	
a. Uncontrolled Impact - Ruptures tanks or lines and causes propellants to mix, 4% H_2, 2% O_2 min. and local pressures of 2 mm Hg or more.	RCS failure causes impact of vehicles, rupturing both propellant tanks/lines and causes propellants to mix and generate enough pressure to lead to fire/explosion.
3. Transfer	
a. Erratic Fuel Flow to GG (Gas Generator) - Liquid sloshing uncovers fuel inlet.	Zero "G" propellant shift can cause GG propellant inlet to uncover and lead to combustion instability and GG burnout and fire/explosion.
b. Instability of H/E (Heat Exchanger)	Erratic operation of GG could lead to oscillations in H/E, destroy H/E and lead to fire/explosion.
c. Structural Failure - Due to overall vehicle dynamic instability.	Dynamic instability could cause leakage into any confined volume which could raise pressure to 2 mm Hg and result in fire/explosion when ignited by shock, friction or catalytic action.

Table 4.1.2-1 (Continued)
CONDITIONS CONTRIBUTING TO FIRE AND EXPLOSION HAZARDS
(Hazard Group 1)

3. Transfer (Continued)	
d. Improper Control of GG Regulators	Excess O_2 can cause over-temperature and burn-through of the GG - H/E Unit.
e. Mixing of H_2 - O_2	Any confined mixing of H_2 - O_2 can lead to conditions described in rationale 1.a.
4. Retrieval	
a. Fluids in Cargo Bay - H_2 accumulates in cargo bay to 4% or more in air.	Hydrogen leaking into cargo bay will combine with air diffusing in and be expected to cause fire/explosion on re-entry.
b. Loss of Tank Pressure - Causes implosion on re-entry.	Pressure below structural limits of ambient would cause tank to implode, release H_2 which would mix with air and explode.
c. Venting in Cargo Bay - During re-entry, releases H_2.	Any hydrogen which vents in cargo bay during re-entry can cause fire/explosion.
d. Improper Stowing - Allows module to shift and rupture tank.	If not locked in place, deceleration could cause shift and rupture of tank, release H_2 and lead to fire/explosion.

Table 4.1.2-2
CONDITIONS CONTRIBUTING TO PRESSURIZATION HAZARDS
(Hazard Group 2-1)

1. Deployment - Pressurization System Inoperative	
2. Docking - Pressurization System Inoperative	
3. Transfer	
a. <u>Vent Valve Failure</u> - Tank overpressure blows rupture disc.	Rupture disc blowing out renders system inoperative, tank pressure depletes, fluids are lost from disc opening. Loss of tank pressure prevents re-entry.
b. <u>GG Instability</u>	Zero "G" propellant shift can cause GG propellant inlet to uncover and lead to combustion instability and GG burnout and fire/explosion.
c. <u>H/E Instability</u>	Erratic operation of GG could lead to oscillations in H/E, destroy H/E and lead to fire/explosion.
d. <u>Loss of remote control of GG and H/E</u>	Inability to terminate gas flow would create excess vent gas to contaminate area. Excessive temperature could cause fire/explosion.
4. Retrieval	
a. <u>Loss of Tank Pressure</u> - Causes implosion on re-entry.	Pressure below structural limits of ambient would cause tank to implode, release H_2, which would mix with air and explode.

Table 4.1.2-3
CONDITIONS CONTRIBUTING TO THERMAL SHOCK HAZARDS
(Hazard Group 2-2)

1. Deployment	
a. Thermal Shock - From tank, line rupture or vented gases.	Fluids ejected will freeze into solids and deposit on vehicle surfaces and fail parts incapable of resisting shock such as TV lens, floodlights, etc.
2. Docking	
a. Thermal Shock - from tank, line rupture or vented gases.	Fluids ejected will freeze into solids and deposit on vehicle surfaces and fail parts incapable of resisting shock such as TV lens, floodlights, etc.
3. Transfer	
a. Rapid Childown of System	Childown that is too fast can locally over-stress system components.
b. Blowing Leak, Cracks H/E or GG	Solids deposited on H/E and GG surfaces can crack assembly not designed for thermal shock.
4. Retrieval	
a. Thermal Shock - From tank, line rupture or vented gases.	Fluids ejected will freeze into solids and deposit on vehicle surfaces and fail parts incapable of resisting shock such as TV lens, floodlights, etc.

Table 4.1.2-4
CONDITIONS CONTRIBUTING TO LINE INTERCONNECT FIXTURE HAZARDS
(Hazard Group 2-3)

1. Deployment	
a. <u>Index Probes Fail to Release</u>	Attempts to translate module that is not released will damage fixture, cause leakage, and prevent reconnect.
b. <u>Quick Disconnect (QD) does not seat on separation</u>	Leakage or mass spill. Dual leakage into any confined volume could raise pressure to 2 mm Hg and result in fire/explosion when ignited by shock, friction or catalytic action. When index probes unlock but do not fully release, movement of the module could rupture both lines if on one fixture. Local pressure by impinging fluids could be high enough to lead to fire/explosion. Fluids ejected will freeze into solids and deposit on vehicle surfaces and fail parts incapable of resisting shock such as TV lens, floodlights, etc.
2. Docking	
a. <u>QD Damaged and Leaks</u>	See 1.a. rationale.
b. <u>Electrical Connectors Damaged</u>	Electrical connector damage would lead to inability to command/control or transmit data to/from assembly.

Table 4.1.2-4 (Continued)
CONDITIONS CONTRIBUTING TO LINE INTERCONNECT FIXTURE HAZARDS
(Hazard Group 2-3)

3. Transfer	
a. Indexing Probes Fail to rigidize fixture	Attempts to mate without rigidization could damage mating lines/connectors. See 1.a. rationale.
b. Electrical Connectors Damaged when Extended	Non-rigidization of line interconnect fixture could cause misalignment.
c. Line Extension Bellows Ruptures on Actuation	Extended use could cause bellows to fail and cause leakage of propellants.
d. Failure to Seal QD on Mating	Dual leakage into any confined volume could raise pressure to 2 mm Hg and result in fire/explosion when ignited by shock, friction or catalytic action.
	When index probes unlock but do not fully release, movement of the module could rupture both lines if on one fixture. Local pressure by impinging fluids could be high enough to lead to fire/explosion.
	Fluids ejected will freeze into solids and deposit on vehicle surfaces and fail parts incapable of resisting shock such as TV lens, floodlights, etc.
e. Failure to Retract lines	Attempts to translate module that is not released will damage fixture, cause leakages, and prevent reconnect.
f. Index Probes Fail to Release	Same as 3.e. above.

Table 4.1.2-4 (Continued)
CONDITIONS CONTRIBUTING TO LINE INTERCONNECT FIXTURE HAZARDS
(Hazard Group 2-3)

3. Transfer (Continued)	
g. <u>Propulsive Leakage</u>	The propulsive effects of leaking fluids could impart thrust vectors the RCS could not correct, or lead to restricted vision.
h. <u>Rapid Childown of System</u>	Bellows and connections within the line interconnect fixture would be subjected to overstressing.
4. Retrieval	
a. <u>Improper Stowing Preventing Line Interconnect Fixture Mating</u>	The location of attach points relating to fixture indexing is critical to the successful mating of the fixture.
b. <u>Indexing Probes Fail to Rigidize Fixture</u>	Attempts to mate without rigidization could damage mating lines/connectors.
c. <u>Electrical Connectors Damaged when Extended</u>	Same as 4.b. above.
d. <u>Failure to Seal QD on Mating</u>	See rationale in 3.d. above.
e. <u>Fluids in Cargo Bay</u> - H_2 accumulates in cargo bay to 4% or more in air.	Hydrogen leaking into cargo bay will combine with air diffusing in and be expected to cause fire/explosion on re-entry.
f. <u>Loss of Tank Pressure</u> - Causes implosion on re-entry.	Pressure below structural limits of ambient would cause tank to implode, release H_2 which would mix with air and explode.
g. <u>Venting in Cargo Bay</u> - During re-entry, releases H_2.	Any hydrogen which vents in cargo bay during re-entry can cause fire/explosion.

Table 4.1.2-5
CONDITIONS CONTRIBUTING TO LEAKAGE/MASS SPILL HAZARDS
(Hazard Group 2-4)

1. Deployment	
a. <u>Quick Disconnect (QD) does not Seat on Separation</u>	Dual leakage into any confined volume could raise pressure to 2 mm Hg and result in fire/explosion when ignited by shock, friction or catalytic action.
	When index probes unlock but do not fully release, movement of the module could rupture both lines if on one fixture. Local pressure by impinging fluids could be high enough to lead to fire/explosion.
	Fluids ejected will freeze into solids and deposit on vehicle surfaces and fail parts incapable of resisting shock such as TV lens, floodlights, etc.
b. <u>Tank Rupture</u> - Causing fluids to mix, 4% H_2, 2% O_2 min. at 2 mm Hg or more pressure.	Dual leakage into any confined volume could raise pressure to 2 mm Hg and result in fire/explosion when ignited by shock, friction or catalytic action.
c. <u>Line Rupture</u> - Occurring when index probes did not release.	When index probes unlock but do not fully release, movement of the module could rupture both lines if on one fixture. Local pressure by impinging fluids could be high enough to lead to fire/explosion.
d. <u>Meteoroid Penetration</u>	Meteoroids larger than 1 gm mass would penetrate tanks and lead to mass spills.
e. <u>Penetration by Space Debris</u>	Impact with any space debris could cause potential leakage problems.

Table 4.1.2-5 (Continued)
CONDITIONS CONTRIBUTING TO LEAKAGE/MASS SPILL HAZARDS
(Hazard Group 2-4)

2. Docking	
a. Uncontrolled Impact - Ruptures tanks or lines and causes propellants to mix, 4% H_2, 2% O_2 min., and local pressures of 2 mm Hg or more.	RCS failure causes impact of vehicles, rupturing both propellant tanks/lines and causes propellants to mix and generate enough pressure to lead to fire/explosion.
3. Transfer	
a. Dynamic Loading of Interfaces	Vehicle instability from any cause could lead to "working" and leakage at connections.
b. Indexing Probes fail to Rigidize Fixture	Attempts to mate without rigidization could damage mating lines/connectors.
c. Line Extension Bellows Ruptures on Actuation	Extended use could cause bellows to fail and cause leakage of propellants.
d. Flex Lines Rupture	Freezing of storables could lead to rupture of flex lines when bent.
e. Vent Valve Failure - Tank overpressure blows rupture disc.	Rupture disc blowing out renders system inoperative, tank pressure depletes, fluids are lost from disc opening. Loss of tank pressure prevents re-entry.
4. Retrieval	
a. Index Probes Fail to Release	Attempts to translate module that is not released will damage fixture, cause leakage, and prevent re-connect.
b. Quick Disconnect (QD) does not Seat on Separation	Leakage or mass spill. See rationale in 1.a. above.

Table 4.1.2-5 (Continued)
CONDITIONS CONTRIBUTING TO LEAKAGE/MASS SPILL HAZARDS
(Hazard Group 2-4)

4. Retrieval (Continued)	
c. <u>Uncontrolled Impact</u> - Ruptures tanks or lines and causes propellants to mix, 4% H_2, 2% O_2 min., and local pressures of 2 mm Hg or more.	RCS failure causes impact of vehicles, rupturing both propellant tanks/lines and causes propellants to mix and generate enough pressure to lead to fire/explosion.
d. <u>Line Rupture</u> - Occurring when index probes did not release.	When index probes unlock but do not fully release, movement of the module could rupture both lines if on one fixture. Local pressure by impinging fluids could be high enough to lead to fire/explosion.
e. <u>Indexing Probes Fail to Rigidize Fixture</u>	Attempts to mate without rigidization could damage mating lines/connectors.

Table 4.1.2-6
CONDITIONS CONTRIBUTING TO LIQUID/VAPOR INTERFACE CONTROL HAZARDS
(Hazard Group 2-5)

1. Deployment - Liquid/Vapor Interface not applicable.

2. Docking - Liquid/Vapor Interface not applicable.

3. Transfer

a. <u>Instability during rotational acceleration</u>	Vehicle instability due to dynamic coupling, CG excursion, sloshing, propulsive venting and RCS failure could lead to loss of liquid/vapor interface control. See hazards in Tables 4.1.2-10, -12, -13, -14, and -15.
b. <u>Instability during Linear Acceleration</u>	Vehicle instability due to CG excursion, sloshing and RCS failure could lead to loss of liquid/vapor interface control. See hazards in Tables 4.1.2-10, -12, and -14.
c. <u>Boiling propellants in Capillary Channels</u>	Loss of insulation or thermodynamic vent failure could cause boiling in capillary channels.
d. <u>Premature Wetting of Self-Wicking Screen</u>	Wetting of screens prematurely would prevent the passage of gases and trap bubbles in the liquid.
e. <u>Structural Failure of Capillary Screens or Baffles</u>	Failure could be caused by sloshing, acceleration, or solidified particles.
f. <u>Buckling of Positive Displacement Diaphragms</u>	Over-pressurization could over-extend bellows or diaphragms.
g. <u>Inability to Purge Positive Displacement Devices</u>	Inability to eliminate liquids from the convolutions of bellows could lead to loss of liquid/vapor interface control.
H. <u>Leaking Diaphragms or Bellows</u>	Leakage of gas into liquids or vice versa could lead to loss of liquid/vapor interface.

Table 4.1.2-7
CONDITIONS CONTRIBUTING TO THE DEGRADATION OF MAN-RATING HAZARDS
(Hazard Group 2-6)

1. Deployment - Not unique to Propellant Logistics Operations	
2. Docking - Not unique to Propellant Logistics Operations	
3. Transfer	
a. All the other hazards are contributors to degrading man-rating when manned element is attached.	The identified hazards could affect the orbiter directly or indirectly and cause damage or injure crew.
b. Failure of Non-Man-Rated Systems with Manned Element Attached	Not all systems of a module are active when attached to the orbiter, propellant pumps, GG, H/E, as examples. The inadvertent actuation of these systems would introduce hazards to the orbiter.
4. Retrieval	
a. Loss of Tank Pressure - Causes implosion on re-entry.	Pressure below structural limits of ambient would cause tank to implode, release H_2, which would mix with air and explode.
b. Fluids in Cargo Bay - H_2 accumulates in cargo bay to 4% or more in air.	Hydrogen leaking into cargo bay will combine with air diffusing in and be expected to cause fire/explosion on re-entry.

Table 4.1.2-8
CONDITIONS CONTRIBUTING TO CONTAMINATION HAZARDS
(Hazard Group 3)

1. Deployment	
a. Thermal Shock - From tank, line rupture or vented gases.	Fluids ejected will freeze into solids and deposit on vehicle surfaces and fail parts incapable of resisting shock such as TV lens, floodlights, etc.
b. Quick Disconnect (QD) does not Seat on Separation	Leakage or mass spill. Same as 1.a. above.
2. Docking	
a. Uncontrolled Impact Ruptures Tank or Line	Fluids ejected will freeze into solids and deposit on vehicle surfaces, contaminating lens, etc.
3. Transfer	
a. Obscured Vision	Venting obscures transfer area.
b. Plume Impingement	RCS exhaust directed toward orbiter could cloud viewing ports (Apollo).
4. Retrieval	
a. Quick Disconnect (QD) does not Seat on Separation	Same rationale as 2.a. above.

Table 4.1.2-9
CONDITIONS CONTRIBUTING TO IMPACT HAZARDS
(Hazard Group 8)

1. Deployment	
a. <u>Sloshing of Propellants</u>	Instability caused by sloshing could cause module to impact cargo bay walls or doors because of manipulator arm flexing.
b. <u>Propulsive Venting</u>	The thrust due to propulsive venting could flex manipulator arms and cause module to impact cargo bay walls or doors.
c. <u>Propulsive Leakage</u>	The thrust from propulsive leakage from tank penetration or failure could flex manipulator arms and cause module to impact cargo bay walls or doors.
2. Docking	
a. <u>Misalignment of Docking Fixture</u>	Misalignment by propulsive leakage or venting, RCS action, sloshing or human error could lead to impact damage to docking.
b. <u>RCS action with Module Extended on Manipulator Arms</u>	RCS action could force the module to impact with adjacent vehicles by flexing manipulator arms.
c. <u>Failure of Structural Supports</u>	When deploying by rotation, failure of the support braces would allow the tank module and tug to impact the orbiter in the crew compartment.
3. Transfer	
a. <u>Meteoroid Impact</u>	Impact by meteoroids larger than 1 gm mass would cause structural damage.
b. <u>Impact by Space Debris</u>	Impact by space debris could cause damage.
4. Retrieval	
a. <u>Sloshing of Propellants</u>	See Rationale in 1.a. above.

Table 4.1.2-10
CONDITIONS CONTRIBUTING TO ATTITUDE CONTROL HAZARDS
(Hazard Group 9)

1. Deployment	
a. Propulsive Venting	The thrust produced by propulsive venting could overcome capability of RCS to regain control.
b. Propulsive Leaking	The thrust produced by propulsive leakage could overcome capability of RCS to regain control.
c. Intermittent RCS with Module on Manipulators	Instability caused by sloshing could introduce dynamic forces accentuating the instability.
2. Docking	
a. Impact from Misalignment causes Small Mass to Rotate	Misalignment during docking of a small mass to larger mass could cause smaller to tumble and impact larger mass and damage one or both.
b. Loss of Docking Interface Rigidization	Damage of interface connections or tumble and misalignment during docking of a small mass to larger mass could cause smaller to tumble and impact larger mass and damage one or both.
c. Depletion of RCS Propellants (Tug)	The tug RCS uses propellants from main tanks with no RCS reserve. Loss of propellant consumption data could lead to loss of vehicle control.

Table 4.1.2-10 (Continued)
CONDITIONS CONTRIBUTING TO ATTITUDE CONTROL HAZARDS
(Hazard Group 9)

3. Transfer	
a. Dynamic Coupling	Overall vehicle dynamics could lead to amplified oscillations and damage to one or both.
b. Fluid Sloshing	The shifting of propellants can cause CG shifts and affect attitude control.
c. Wobble during Rotational Transfer	Wobble can be introduced by disturbances which affect vehicle control.
d. Loss of Data on Propellant Quantity	Overfill could cause loss of liquids through vents. See contamination hazard. Underfill could result in 2.c. of this Table.
e. Structural Failure during Spinup, Despin	RCS failure could lead to high rotational forces and structural failure or inability to despin.
f. Meteoroid Penetration	Can lead to propulsive leakage that would overcome the capability of RCS to retain vehicle control.
g. Impact by Space Debris	Impact energy of collision with space debris could introduce linear translation or rotation and loss of vehicle control.
4. Retrieval	
a. Uncoordinated Manipulator Operation	Unsynchronized movement of the two manipulator arms would cause module to rotate or translate and lead to loss of vehicle control.
b. Propulsive Venting	The thrust produced by propulsive venting could overcome capability of RCS to regain control.
c. Index Probes Fail to Release	Attempts to translate module that is not released could result in loss of vehicle control.

Table 4.1.2-11
CONDITIONS CONTRIBUTING TO COMMUNICATION HAZARDS
(Hazard Group 11)

1. Deployment - Not unique to Propellant Logistics Operations.
2. Docking - Not unique to Propellant Logistics Operations.
3. Transfer

a. <u>Communications Blackout</u>	During rotation the antenna may be shielded from ground or orbital receivers.
b. <u>Electrical Connector Failure</u>	Electrical power failure at interface would interrupt communications.

Table 4.1.2-12
CONDITIONS CONTRIBUTING TO SLOSHING HAZARDS
(Hazard Group 12-1)

1. Deployment	
a. <u>RCS action with Module Extended on Manipulator Arms</u>	RCS action would initiate fluid movement that could amplify by flexing manipulator arms.
b. <u>Erratic Operation of Deployment Mechanism</u>	Intermittent or interrupted movement by binding or poor control could introduce fluid oscillation.
c. <u>Impact During Deployment when Attached to Manipulator</u>	Impact of module could initiate sloshing. A 60,000 lb. module, moving 0.5 ft/sec has 30,000 ft/lb of stored energy that could be released by sloshing.
d. <u>Propulsive Leakage</u>	The thrust of propulsive leakage could initiate sloshing.
e. <u>Propulsive Venting</u>	The thrust due to propulsive venting could flex manipulator arms and initiate sloshing.
2. Docking	
a. <u>Misalignment of Docking Fixture</u>	Misalignment due to propulsive leakage or venting, RCS action, sloshing or human error could lead to impact damage.
b. <u>Loss of Docking Interface Rigidization</u>	When the interface is not rigidized any action by the RCS will allow uncoordinated movement causing sloshing.

Table 4.1.2-12 (Continued)
CONDITIONS CONTRIBUTING TO SLOSHING HAZARDS
(Hazard Group 12-1)

3. Transfer	
a. <u>Dynamic Coupling</u>	Overall vehicle dynamics could lead to amplified oscillations and cause sloshing.
b. <u>Fluid Surface Distortion</u>	Excessive flow rates can break through fluid surface and initiate random movement and sloshing.
c. <u>Propulsive Leakage</u>	The thrust of propulsive leakage could initiate sloshing.
d. <u>Propulsive Venting</u>	The thrust of propulsive venting could initiate sloshing.
4. Retrieval	
a. <u>Erratic Operation of Deployment Mechanism</u>	Intermittent or interrupted movement by binding or poor control could introduce fluid oscillation.

Table 4.1.2-13
CONDITIONS CONTRIBUTING TO DYNAMIC COUPLING HAZARDS
(Hazard Group 12-2)

1. Deployment	
a. RCS action with Module Extended on Manipulator Arms	RCS action coupled with manipulator arm flexing and sloshing could lead to amplified oscillations.
2. Docking	
a. RCS action when Vehicles are Captured but not Rigidized	Passive vehicle will lag active vehicle and RCS action could over-correct and cause oscillations which could be amplified by sloshing.
3. Transfer	
a. Any condition contributing to loss of vehicle control during transfer (Table 4.1.2-10, item 3)	Combination and interaction of conditions applied to specific configuration can cause dynamic coupling hazard, leading to structural failure. Overall vehicle dynamics must be evaluated.
4. Retrieval	
a. Separation attempt before Complete Docking Release	Same rationale as 2.a. above.
b. RCS Action with Module Extended on Manipulator Arms	Same rationale as 1.a. above.

Table 4.1.2-14
CONDITIONS CONTRIBUTING TO CG CONTROL HAZARDS
(Hazard Group 12-3)

1. Docking	
a. Failure to Achieve Rigidization During Docking	Failure to achieve rigidization could cause rotation to occur about the CG of the docking elements. The rotation could be caused by impact during docking attempt. Where one element is of modular construction, the CG is offset such that the rotation could be in either direction depending on the location of the docking port relative to the CG. The combined configuration would be difficult to control under this condition.
2. Transfer	
a. Loss of Data on Quantities of Propellants Transferred	In this case, insufficient propellant loading can cause instability in the CG location due to sloshing. If overfill is made because of loss of quantity data the hazard could be an improper orbit in mission placement of the payload.
b. Intermittent RCS Operation While Docked to Modular Element	While docked to an element of modular construction, intermittent operation of the RCS of the docked vehicle could cause movements around the CG of the coupled configuration which could cause adverse effects on the elements.

Table 4.1.2-15
CONDITIONS CONTRIBUTING TO UNCONTROLLED VENTING HAZARDS
(Hazard Group 12-4)

1. Deployment	
a. Propulsive Venting	With the tank vent valve failed in the open position, the tank will vent uncontrolled. The tank must remain in orbit until all propellants have sublimed out of the tank. With internal tank pressure being at ambient (vacuum), the tank cannot be returned to earth until it has been repaired and able to maintain pressure (14.7 psi). The descent during deorbit would implode the tank due to pressure differential.
b. Propulsive Leakage	See rationale in 1.a. above.
2. Docking	
a. Propulsive Venting	See rationale in 1.a. above.
b. Propulsive Leakage	See rationale in 1.b. above.
3. Transfer	
a. Loss of Vapor Control	Capability may be lost where the thermal protection insulation is damaged such that excess heat is transferred to the propellants causing venting. Failure of the thermodynamic vent system could cause loss of cooling to the O_2 tankage which could then cause loss of vapor control resulting in uncontrolled venting.

Table 4.1.2-15 (Continued)
CONDITIONS CONTRIBUTING TO UNCONTROLLED VENTING HAZARDS
(Hazard Group 12-4)

3. Transfer (Continued)	
b. <u>Over-pressurization</u>	Loss of control to the gas generator and heat exchanger could cause the vent valve to continuously relieve the tank. If the capability to relieve through the vent valve was exceeded the burst disc would then function. This then leads to uncontrollable venting.
c. <u>Propulsive Venting</u>	See rationale in 1.a. above.
d. <u>Propulsive Leakage</u>	See rationale in 1.b. above.
4. Retrieval	
a. <u>Loss of Tank Pressure</u> - Causes implosion on re-entry.	The rationale for this is essentially the same as for the "tank vent valve fails in open position" in the deployment operation hazard.

4.2.1.1 Propellant Loading - Propellant Tank Module in Cargo Bay

The propellant logistic element will be loaded into the cargo bay while the orbiter is in the horizontal position. During this operation, the propellant logistic element will be lowered and properly secured to the orbiter cargo bay attach points. Because of the lack of volumetric clearance for a man in the orbiter cargo bay, the remote monitoring of this operation by TV aids is expected. The shuttle orbiter literature presently does not describe connect points in the cargo bay for propellant loading, pressurization, venting, etc. Therefore, for purposes of this study, it is assumed there will be a line interconnect fixture and venting system capable of providing necessary services to the propellant logistic element tankage after mounting in the cargo bay. These connections should be ground checked for leakage and should not present any unique hazard.

Once in the vertical position on the pad, environmental control (nitrogen purge) of the cargo bay is initiated which reduces the explosive hazards unless a major leak develops during propellant loading. This leak occurrence would be a comparable situation to a major leak into the inter-stage area of the S-II/S-IC. The question of whether a series or parallel propellant loading technique is used to load the propellant tank module is therefore investigated.

A discussion of conceptual approach is in order relating to system safety. Safety criteria are provided for use in development of the discussion as follows:

a. The propellant loading operation for the logistic element in the cargo bay should be compatible with the time line for orbiter loading.

b. Fluid lines and connections shall be separated within practical limits to prevent fluid vapor mixing.

c. The cargo bay shall be purged by a gaseous nitrogen purge immediately prior to and during propellant transfer, terminating at liftoff.

d. The propellant fill and drain system for the logistic element in the cargo bay shall be sized and configured for emergency off load capability, where off load is by gravity head and accomplished in a time comparable to loading time or less.

e. The line interconnect fixture(s) will be leak and pressure checked by ground operations checkout prior to propellant loading as part of the launch checkout.

f. The allowable concentration in any enclosed area shall be less than 2 percent hydrogen gas by volume where personnel are not in the pad area and 1 percent when they are working in the area.

g. Hazardous gas detection sensors shall provide data for cargo bay leak detection and monitoring purposes.

h. The propellant logistic element tank vents will be connected to the orbiter vent system for disposal of vented hazardous gasses.

Factors bearing on the operation involve (1) the time allotted for propellant loading, (2) feed system pressure head and loading rate, and (3) consideration of design to accommodate series or parallel propellant loading, draining and emergency off load, etc. Table 4.2.1.1-1 presents the safety considerations of a series versus parallel loading operation for propellant logistic elements in the cargo bay.

4.2.1.2 Propellant Loading - Slush

The previous discussion involved LO_2 and LH_2; however, a part of this operation may involve slush H_2. The safety case for slush hydrogen is not as well defined as that for liquid hydrogen. However, hazards can be identified for the gross case and further refinement of a complete slush hydrogen system must be made before other hazards are identified applicable to the system. It is assumed the slush hydrogen will be manufactured within a distance of two miles from the launch pad with two methods postulated for delivery to the launch pad operation: (1) by pumping through highly insulated facility lines directly into the propellant tank when the tanks are located in the cargo bay after erection on the pad, and (2) by loading the propellant module at the slush manufacturing location and transfer, with emplacement of the tank in the cargo bay, at the pad while maintaining the environmental conditions needed in the insulation to prevent heat transfer during the operation. Both of these methods have hazards which are discussed below. Additional discussions are contained in Appendix G.

a. Method 1 (Slush Delivery by Pumping Via Pipeline)

Long line runs requiring super insulation capability afford the potential for failure of the insulation quality causing heat leaks and liquification of the slush if not flowing, as during a hold condition. This could lead to slug flow. At a critical velocity of slush in a 17 mm line (about 0.46 m/sec.) which corresponds to a Reynolds number of 2.3×10^4, Ref. No. 52, the ice will settle out of the liquid and could cause line blockage due to some restriction in the system. This blockage could also occur during hydrogen propellant tank draining where the outlet bridges over with ice crystals as the fluid drains out. These residuals could be hazardous.

Table 4.2.1.1-1
SERIES VS. PARALLEL LOADING PROPELLANT LOGISTICS ELEMENTS

CONDITION	SERIES LOADING POTENTIAL RISK	PARALLEL LOADING POTENTIAL RISK	COMMENT
1. Rate of flow per given time	Higher LO_2 & LH_2	Lower LO_2 & LH_2	Shorter time for series loading per fluid gives higher flow rate.
2. Fire Potential	Higher	Lower	Greater amount of LO_2 available per given time for reaction in series system.
3. Explosive Potential	Lower	Higher	Quantity of LH_2 per given time for mixing greater in parallel system.
4. Drain Time	Lower	Higher	Relates to larger line size of series system.
5. Element fed from orbiter LH_2-LO_2 main tankage propellant loading system	Lower	Higher	Main system failure for parallel loading presents more hazard effects.
6. Element fed from separate propellant loading system	Lower	Higher	Separation of fluids presents fewer hazards
7. Potential mixing at line interconnect fitting having LH_2 & LO_2 lines in one fixture	Lower	Higher	Time spaced flow prevents mixing in series loading.
8. Potential mixing where line interconnect fixture has only one LH_2 or LO_2 line by use of 2 fixtures	Lower	Higher	Time spaced flow plus separation of lines best in series loading.
9. Emergency offload through a fixture having both LH_2 & LO_2 lines	Higher	*	Provides mixture capability leading to fire/explosion if purge fails. Series system lines larger.

Table 4.2.1.1-1
SERIES VS. PARALLEL LOADING PROPELLANT LOGISTICS ELEMENTS (Cont.)

CONDITION	SERIES LOADING POTENTIAL RISK	PARALLEL LOADING POTENTIAL RISK	COMMENT
10. Emergency offload through 2 fixtures, each having one propellant line; i.e., LH_2 or LO_2	Lower	*	Greatly reduces mixing potential in case of purge failure. Series system line larger.
11. Combination of 2 & 9	Higher	*	Greater than 12 while in earth's atmosphere
12. Combination of 2 & 10	Lower	*	Least risk for ground operations
OVERALL RISK	Lower	Higher	

*In emergency offloadings, parallel offloading through separate series systems would be used.

Where the insulation heat leak allows the slush to reach the triple point, the expansion of the hydrogen slush to liquid (approximately 16 percent for 50% slush, Ref. No. 12) could be expected to cause two-phase (gas and liquid) flow in the vent system. [The hazard is the system may not be designed to take this two-phase flow.]

b. Method 2 (Slush Delivery by Module)

Low thermal conductivity insulation environment would have to be maintained on the propellant tank module through the entire period from loading, cargo bay installation, and launch. The fire/explosion potential in case of failure during a manual operation is too hazardous and should be prohibited. The fact that the module may be controlled and emplaced in the cargo bay by automatic means does not lessen the fire/explosion hazard. A hold for a long period of time or ground abort condition could initiate conditions for a fire or explosion.

4.2.1.3 Conclusions

Evaluation of the hazards leads to the following safety conclusions involving propellant logistic element tank loading ground operations:

a. A series loading concept with separation of facility lines and interconnect fixtures presents fewer hazards when the propellant logistic element in the cargo bay is loaded by a separate propellant loading system, independent of the booster/orbiter propellant loading system.

b. Although one line interconnect fixture containing both LO_2 and LH_2 lines, pressurization, etc., can be used for safe operation under orbital ambient vacuum conditions, the use of this fixture under emergency off load and drain requirements for ground operation presents potential mixing hazards. This condition suggests either a design driver for preventing any leakage at the interconnect fixture, or separation by use of two interconnect fixtures each containing only one line; e.g., LO_2 or LH_2. An assumption in this case is that in an emergency the off load would be accomplished in parallel through the separate series system.

c. The increased rate of flow for serial loading of propellants to meet the two-hour ground loading requirements for the booster/orbiter increases the rate of flow for propellant logistic element propellant loading over that for transfer in orbit, which will increase the line interconnect fixture line sizes over those necessary for orbital propellant transfer.

This increase in flow rate, however, does not materially increase the hazard except in the case where the line size is small enough to impact the capability to off load under emergency conditions.

This consideration from a safety position is a driver in establishing line sizes for interconnect fixtures or providing separate fill and drain system lines.

d. Before the use of slush hydrogen is programmed in an operational concept, additional study of the concept design configurations should be made.

4.2.2 Launch and Ascent

In the conceptual system the status of the cargo bay during launch and ascent should remain essentially the same as just prior to launch, except that with the increase in altitude the nitrogen purge will vent from the cargo bay in less than three minutes after launch.

This will not materially add to the hazards since any failure within the first 3 minutes would be expected to be of major proportions. With attainment of higher altitude (approximately 180,000 feet at 3 minutes) the likelihood of fire continually decreases due to ambient vacuum conditions.

One condition however does present a hazard which, if not properly contained, would produce undesired conditions. This condition is the possibility of the propellant tankage vents relieving within the cargo bay (both liquid oxygen and hydrogen simultaneously) causing an explosive mixture with the cargo bay doors shut. This problem is minimized if the tank vent systems are properly designed for fluid separation and containment of vented fluids.

After post injection maneuver main engine cutoff, the cargo bay doors are opened. Failure of the cargo bay doors to fully open or close could cause delay or loss of mission. Another hazard associated with partial door opening worthy of note is the adverse effect on proper operation of the space radiators located in the doors and which support the ECLSS. Abort considerations in this phase are discussed in Section 4.2.7.

4.2.3 Orbital Phase

Operations in this phase involve transfer of propellants, use of deployment mechanisms and soft docking methods, retrieval of down modules, securing elements in the cargo bay and maintenance operations using IVA and EVA. These operations are discussed in the following paragraphs.

4.2.3.1 OMS Propellant Transfer

The OMS tanks in the shuttle orbiter may contain excess propellants which the representative propellant logistics elements could utilize. These propellants could be expected to be transferred on the initial flight into the tug or centaur prior to deployment out of the cargo bay. For this operation, lines from the OMS tanks run through a series of valving and pumps to the line interconnect fixture. This entire operation in space is relatively safe

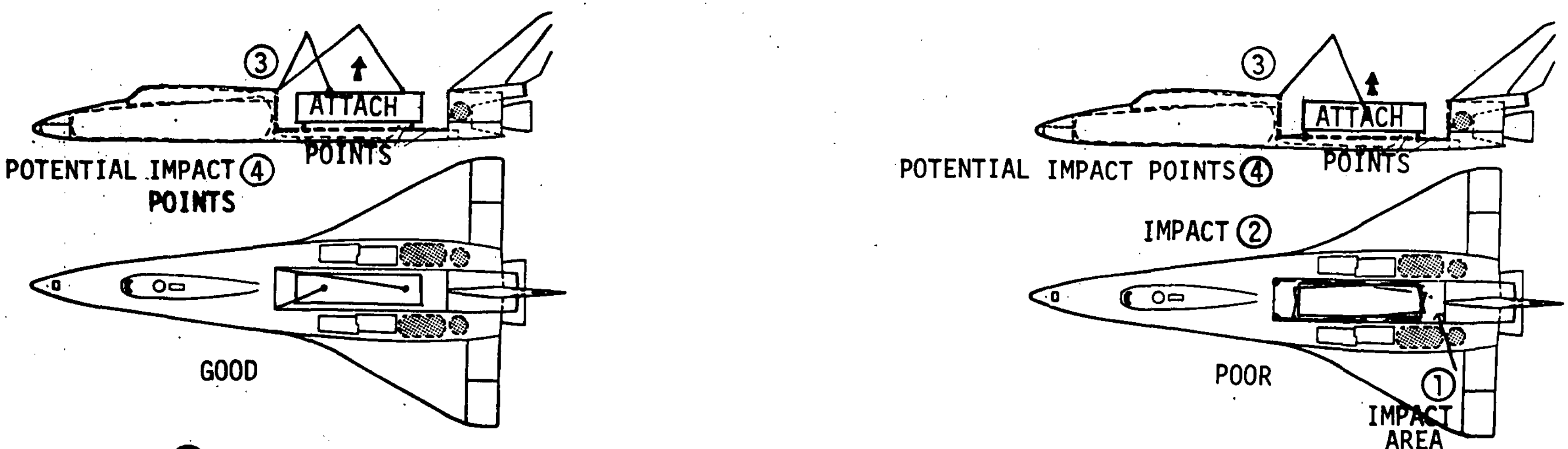
if leakage does not exceed specification requirements. However, large mass spills could be expected to produce snow or ice crystals which could cover the cargo bay walls and propellant tankage or propulsive stage. These crystals could be expected to sublime away over a period of time (hours) from surfaces where heat transfer will occur. However those portions of the snow or ice which are formed in the internal cavities of the orbiter where little or no heat transfers into the surfaces could present a fire/explosive hazard during re-entry. Thus, it is imperative that any rapid drop in line pressure which could signify massive leakage be accompanied with a pump and system cutoff device interlock. See Paragraph 4.2.6 for sublimation of solidified propellants.

4.2.3.2 Deployment

During deployment of the propellant tankage or propulsive stages out of the cargo bay, various hazards are postulated. In the case where the cargo bay doors are not fully opened to provide clearance of the load, any attempt to deploy the load could produce impact damage or reduce the structural integrity of the orbiter cargo bay doors. If the impact is on the radiators of the ECLSS located in the cargo bay doors additional hazards are involved. This then suggests a safety interlock between the cargo bay doors' position and the deployment mechanism control (manipulator and rotational deployment mechanisms). Due consideration must be made in the interlock design to assure once the deployment mechanisms are in a position to preclude the cargo bay doors from normal closure that a failure in the interlock will not prevent the deployment mechanism from being returned into the cargo bay sufficiently to allow the doors to be closed. Deployment mechanisms considered in cargo bay operations included both manipulators and rotational devices. The manipulator concept for deploying large masses in orbit has little state-of-the-art to draw on when it comes to booms of 50 feet or more. It can be postulated that a number of hazards will exist during deployment. These generally involve the location of attach points of the manipulator, the ability to maintain smooth directional control and rate on both manipulator arms during module extraction, and depth perception ability without some type of stereo optics support. Hazards are also associated with the manipulators when the joints operate erratically and where the system fails with the manipulator in a position which precludes cargo bay door closing. See evaluation in Section 6.0.

In the many cases, the introduction of the hazard mode leads to impact. See Figure 4.2.3.2-1.

The rotational mechanism for deployment has built-in stability throughout the deployment operation. In this concept there is a hazard introduced if the module attach fittings of the cargo bay do not properly release prior to an attempt to deploy the module out of the cargo bay. This suggests that an interlock between the attach fitting release mechanism and the deployment mechanism control is required to eliminate possible structural damage/failure.



① IMPACT DUE TO SLIGHT OUT-OF-CONTROL MOVEMENT OF ONE ARM IN FORWARD AFT MOVEMENT
② IMPACT DUE TO ONE ARM UP WITH ONE ARM DOWN
③ DEPTH PERCEPTION INVOLVED WITH ALL OPERATIONS
④ IMPACT DUE TO UNLEVEL EXTRACTION OF MODULE ROTATING THE MODULE ENDS DOWN

Figure 4.2.3.2-1 Deployment Concepts

4.2.3.3 Docking

Propellant logistic element direct docking involves the approach of the two docking vehicles so that the integrally attached docking mechanisms can make contact for initial capture. This system is characterized by the use of the propulsive capability of one of the mating vehicles to effect final closure and docking contact and a relative short and stiff impact attenuation stroke of the docking system. Typically, this stroke is approximately ten (10) inches or less. This direct docking characterizes the mode used where the propellant tankage or propulsive stage is rotated out of the cargo bay. The direct docking system requires the dissipation of relatively large energy levels because of the coarse velocity control expected for propulsive maneuvers and the movement of the large masses involved. In direct docking, one of the vehicles is passive and stabilized prior to the docking operation. Failure to inhibit attitude hold on the passive vehicle presents the hazard where both control systems (active and passive vehicle) are attempting to hold their respective misaligned attitudes after an initial docking attempt. This could cause extensive structural damage at the docking interface and would occur during the period when the two masses are not rigidized in all degrees of freedom of motion. Heavy docking impact coupled with fluid motion could cause the undesired motion between vehicles.

Docking of propellant logistic elements by use of manipulators controlled from the orbiter affords a larger standoff distance between vehicles than direct docking. In using the manipulators for docking the propellant logistic element (propellant tankage), greater flexibility is provided in alignment and docking where the passive target is not in the same relative state of stabilization as the active vehicle. Since closing velocities will be a function of the operator's control capability, manipulator closing velocities (0.1 ft/sec) will be under better control for the mass, than in direct docking with contact velocities up to one (1) ft. per second. The hazards of the manipulator concept are grossly associated with instability of the mass, at the end of the manipulator. Fluid sloshing, RCS operation, and manipulator dynamics with the mass attached could lead to instability and/or impact. See Paragraph 4.2.8 for propulsive effect of venting or leaking fluids.

Hangups during the docking process where a capture latch is holding the docking port in an unrigidized mode also could present hazards by imparting an undesired rotation to the passive vehicle which could not be controlled by the manipulator control operator. The magnitude of this type of hazard is a function of the maximum offset of the docking port from the CG of the entire configuration, and control operation of the configuration immediately before or after contact.

4.2.3.4 Module Retrieval

Module retrieval by the direct docking method or manipulator concept involves the same general type of hazards as those during module docking. Direct docking for module retrieval, by the orbiter, would place the retrieved module on the docking ring of the cargo bay rotational deployment mechanism. Due to the close proximity of the vehicles and large energy involved in shock

attenuation, the hazards appear to be somewhat greater in the direct docking method than those in the use of manipulators, although control of the module into the cargo bay is estimated to be much more stable by the rotational deployment mechanism. Hazards common to retrieval by either concept involve impact, either through projections; i.e., antenna not retracted, loose material in the cargo bay, etc., or through operator error/faulty equipment. It should be noted that there is no uniform attach point mechanism between modules and the orbiter cargo bay, and where random module retrieval is required in a logistics system, this factor can become a driver in configuration interface design, between the elements and orbiter, for the line interconnect fixture.

4.2.3.5 Cargo Bay Attachment

System Safety can be achieved or negated by the location of attach points. They will have to index to the line interconnect fixture for remote automatic re-connect of lines and vents in the cargo bay, for off loading residual propellants, pressurization, etc. This, in the rotational deployment mechanism concept, could be accomplished when the module is indexed to the mechanism docking ring. With the use of manipulators for emplacement of the module in the cargo bay, the attach points will have to provide the indexing needed for line interconnect fixture mating in the cargo bay. This also is true for vent line re-connects to prevent hazardous vapor venting in the cargo bay. See Figure 4.2.3.5-1 for schematic of problem. The magnitude of the interface problem is shown in Figure 4.2.3.5-2.

4.2.3.6 IVA and EVA Maintenance

Orbital operations involving man-in-the-loop, other than shuttle orbiter personnel, are associated with maintenance or build-up requirements. In a propellant logistic system which is remote, fully automatic, and contains ground control override capability, maintenance will be required for failed components, routine maintenance items, and damage caused by impact. Also included will be items with reduced/deteriorating performance. In those cases other than a large depot, maintenance could be accomplished by return of the element to earth. Where the return to earth is impractical or impossible the use of a crew and or equipment module is required for transfer of crew and equipment.

System Safety requirements dictate that these modules be unmanned during their docking between the orbiter and logistic element scheduled for maintenance. Personnel would then transfer through the shuttle hatch into the module. These transfers will be IVA and the suited maintenance personnel must bring the life support environment in the LSF up to the required level or remain suited during the maintenance operation. The orbiter would remain attached for any evacuation needed during the maintenance process. At least two paths must be available for emergency evacuation or protection of the crews. Figure 4.2.3.6-1 schematically portrays the modules which provide two paths of escape for maintenance crews during IVA.

For the Orbiter Model 176A the location of the shuttle docking port would be changed to a forward upper location of the fuselage; however, the processes would remain the same. For the EVA operations on distant equipment

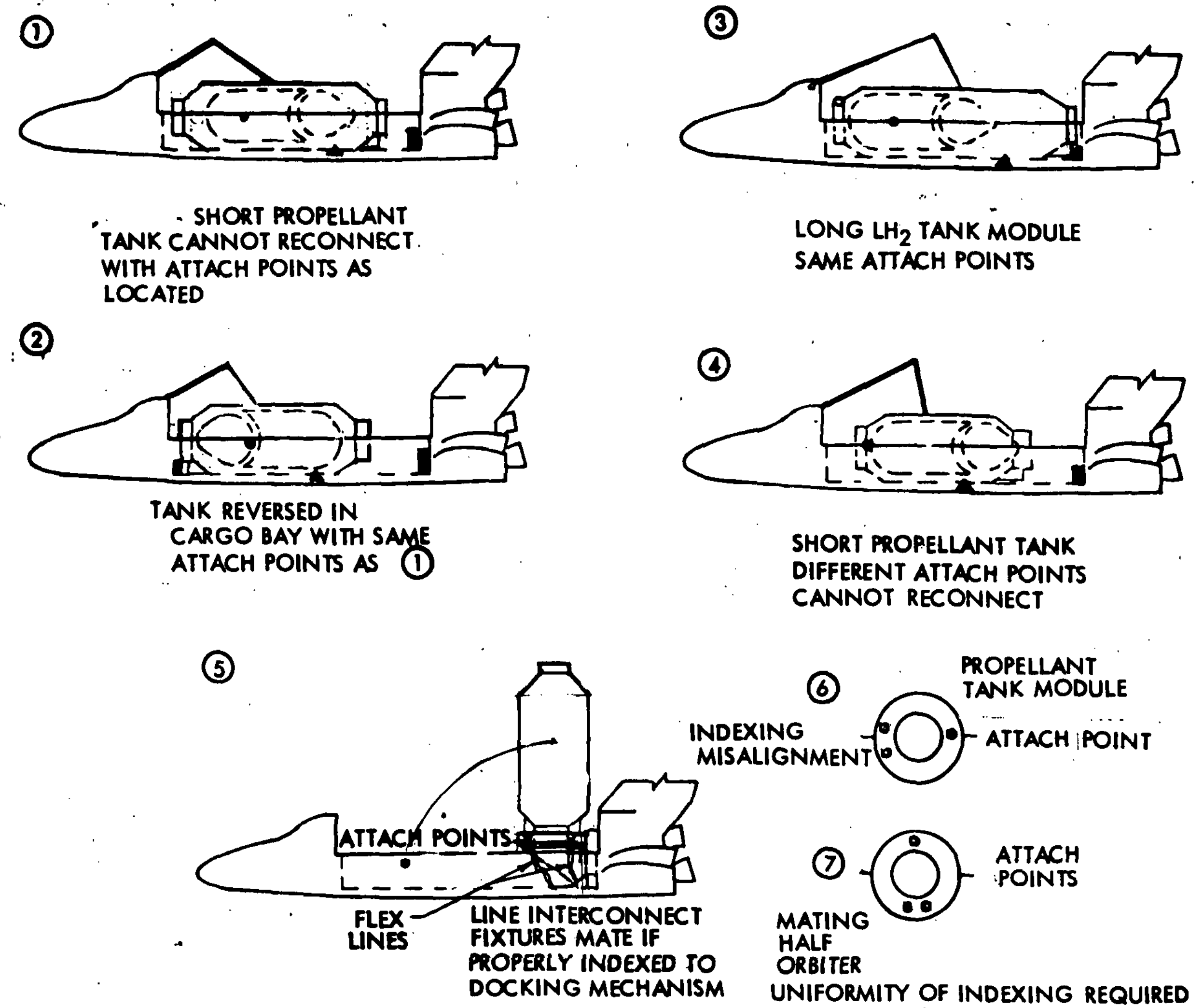


Figure 4.2.3.5-1 Schematic Line Interconnect and Attach Fitting Problems

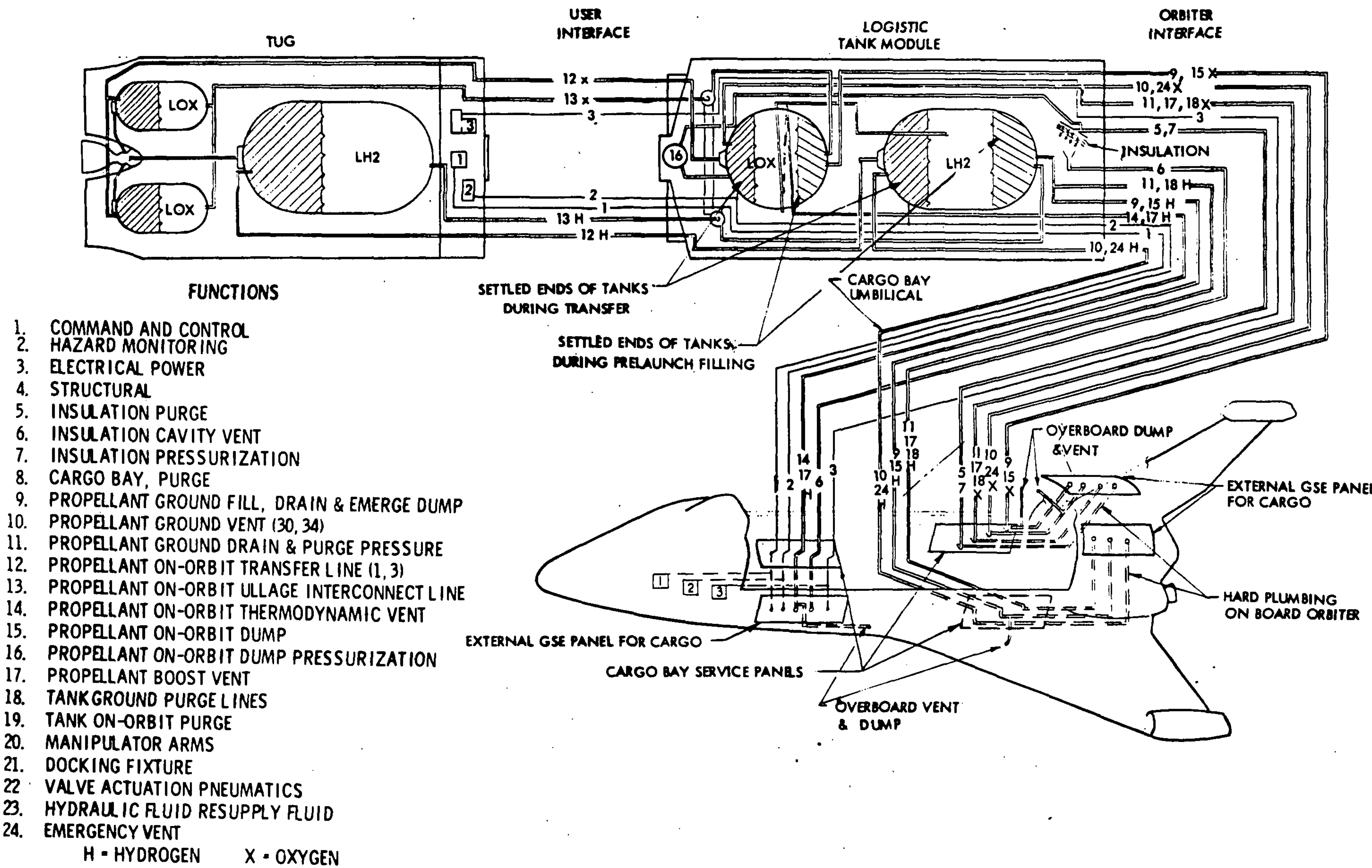


Figure 4.2.3.5-2 Logistic Tank Module Typical Integrated Interfaces Schematic (Preliminary)

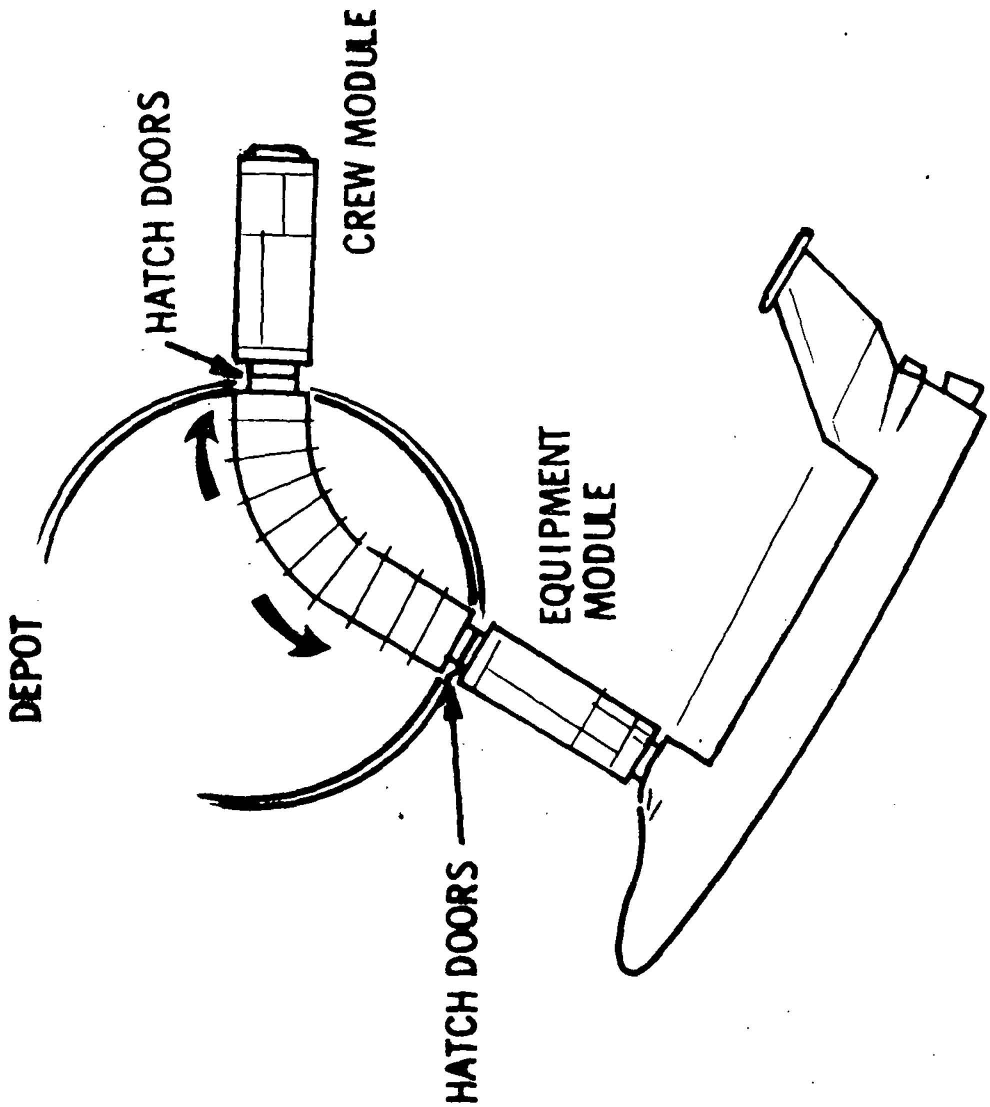


Figure 4.2.3.6-1 Evacuation Route

such as the antenna or RCS packages, the orbiter vehicle may be used for this operation with a suitable stand-off distance from the maintenance location. For this operation two or more EVA-suited maintenance personnel should be working together with an additional EVA-suited crew member standing by to effect rescue operations. His standby position would be in the orbiter docking air lock at a vantage point where he can observe all operations. His location must be provided with a communication capability to direct the orbiter into a position for immediate rescue.

4.2.3.7 Conclusions

Evaluation of the orbital operations leads to the following safety conclusions:

1. Where leakage has occurred within the cargo bay, it must be detected by some means and be sublimed away before re-entry is attempted.

2. Impact damage during deployment and retrieval is a major consideration, the hazards of which produce latent fire/explosion conditions.

3. Both rotational and manipulator deployment mechanisms have advantages which are related to the total operation, each being best for a particular operation. See Section 6.0 for comparison of rotational vs. manipulators.

4. The relation of the attach points to the indexing of the mating line interconnect fixtures is critical.

5. Maintenance operations involving man-in-the-loop should be by IVA. EVA operations should be a "last resort" under any condition.

4.2.4 Deorbit Phase

This phase involves those operations in orbit to prepare the retrieved module for its return to earth. This will encompass not only the aforementioned securing and connect problems but also verification of the integrity of the module to retain pressures at 14.7 psi with no out of specification leakage. Once the returning module has been secured at the attach points and the line interconnect fixtures mated, the pressurization and leak check is accomplished. See Hazard #75 in Appendix C. Floodlights and TV aids are used for all operations. Failure of these aids reduces the data for decision making and could lead to incorrect decisions, creating a hazard. This could be postulated in the case where a pressure decay in the propellant tank module was noted when the tank contained residual propellants. Quantities and location of leaking propellant could not be observed with the aids failed and thus could affect the orbital stay decision to allow time for fluid sublimation, and the decision to remove the module from the cargo bay to determine the leaking condition, etc. These hazards are to be considered latent in their onset and would be expected to become effective in the deorbit phase, causing potential fire or explosion. The risk potential of hydrogen

leaking in the orbiter cargo bay is presented in paragraph 4.2.5.

4.2.5 Hydrogen Leakage into Orbiter Cargo Bay

Because of the leakage hazards identified in the analyses which could occur within, or affect the cargo bay area, a separate assessment was made to develop a technique for establishing the risk potential of hydrogen leaking into the orbiter cargo bay from a propellant tank module carried as cargo.

4.2.5.1 Re-Entry Case

a. Groundrules

If a typical example of a shuttle cargo such as the tug is chosen for analysis the following groundrules can be established:

1. 4% by volume of hydrogen is the minimum percentage necessary to support a combustive or explosive reaction (Reference 21).

2. Hydrogen-oxygen reactions can occur at pressures equal to or greater than 2 mm Hg (Reference 17).

3. No liquid hydrogen remains in the tug hydrogen tank (Reference 13A).

4. Atmospheric oxygen is available for reaction.

5. Every source that can leak hydrogen is leaking at its allowable rate. These leaks are distributed through the entire length of the tug, and the leaking gas mixes intimately in the volume available to it through molecular diffusion.

6. Any hydrogen - oxygen reaction is undesirable. The energy release is dependent on the mass of reacting hydrogen.

b. Determination of Leakage Rate

A typical tug schematic was examined and a total of 233 possible leak points were counted that could be exposed to hydrogen under pressure. These leak points include two 20" diameter manhole covers. Many of these leak points will be welded joints and flared fittings for which the allowable leakage is 5.3×10^{-4} scc/sec (Reference MA0206-1258). If the worst case is assumed and it is assumed that all the leak points are flanged fittings 2-1/2" diameter, the allowable leakage is 0.01 scc/sec/inch of seal (scc - standard cubic centimeters) (Reference MA0206-1255). At this leakage rate, from 233 flanged fittings, a volume of 6.07 scf/day or approximately 1/4 scfh (standard cubic feet per hour) will leak from the tug.

c. Determination of Reaction Volume of Leaking Hydrogen

If the tug is emplaced in the cargo bay and the doors are closed in preparation for re-entry the volume available for reaction is the net volume of the cargo bay minus the cargo volume. See Figure 4.2.5.1-1 and 4.2.5.1-2. The cargo bay volume is 19,400 cubic feet (Reference 59) and the tug volume can be calculated as approximately 2700 cubic feet and the volume available for reaction, the free volume, is 16,700 cubic feet. Of course, larger cargoes or payloads on the tug would reduce the free volume, but not enough to alter the conclusions (see the two points plotted on Figure 4.2.5.1-3).

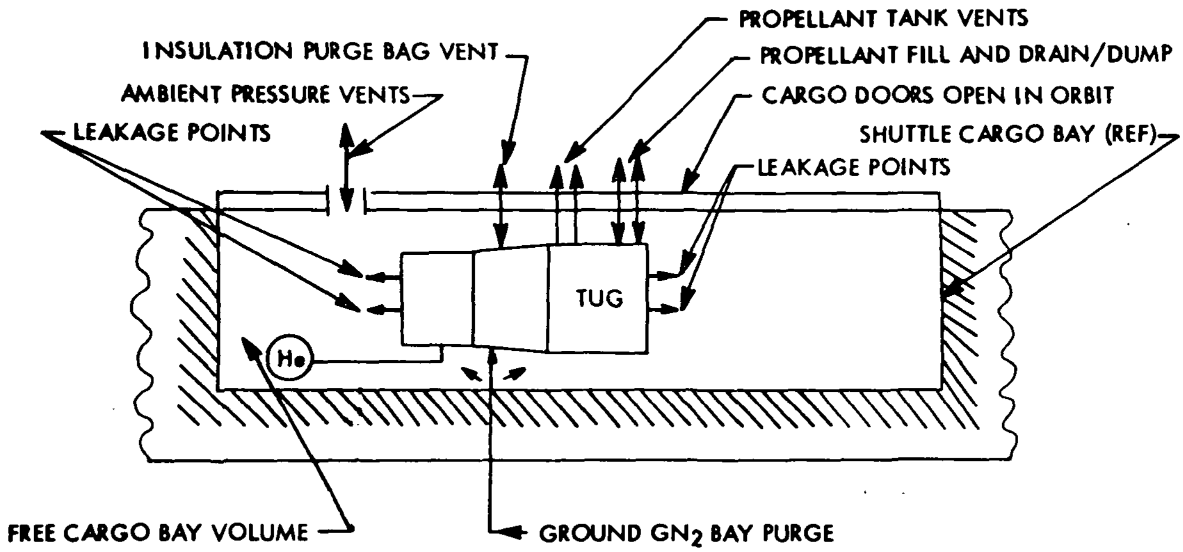


Figure 4.2.5.1-1 Tug Emplaced in Shuttle Cargo Bay

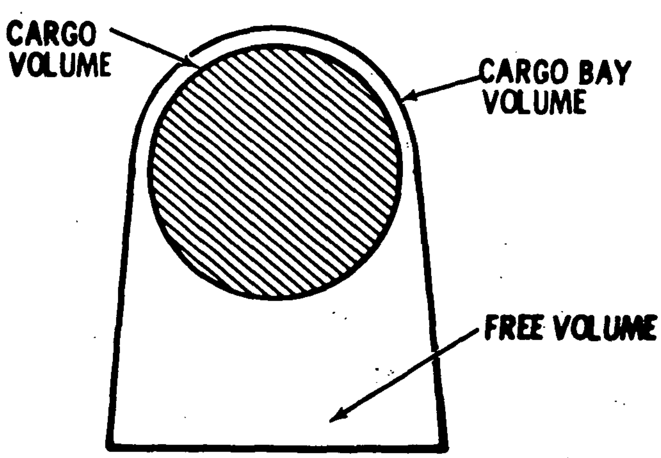


Figure 4.2.5.1-2 Typical Shuttle Cargo Bay Cross Section with Cargo in Place

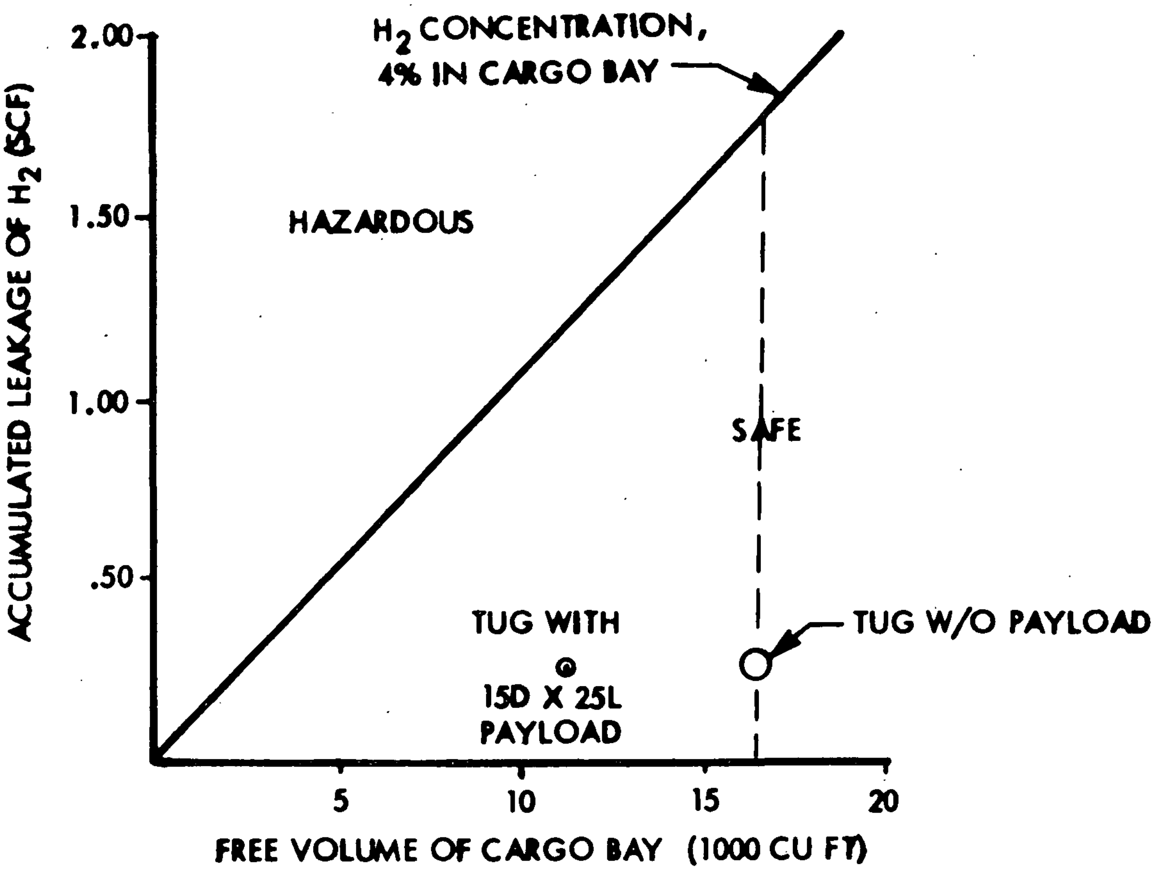


Figure 4.2.5.1-3 H_2 Leakage in Cargo Bay on Re-entry

d. Determination of Hazardous Concentrations

During re-entry preparations, utilizing the current sequence of events, the tug will be emplaced in the cargo bay, the residual liquid hydrogen will be dumped and the tank vented to vacuum and re-pressurized to 17 psia (one or more times). At this time the shuttle will begin its re-entry flight. The tug will continue to leak hydrogen gas from the possible leak points and this hydrogen will accumulate in the free volume when external pressure is greater than cargo bay pressure.

Using internal cargo bay pressure 4.2.5.1-4 (Reference 59) the leaking hydrogen that is expressed as standard cubic feet will expand to fill a larger volume. Since computer programs have not been developed to permit predictions of how much of the leaking hydrogen would diffuse out of the cargo bay the worst case was assumed. If all the leaking hydrogen remained in the cargo bay from time zero (closing cargo bay doors) until cargo bay pressure becomes great enough to permit reactions the leaking hydrogen will expand inverse-ly as the cargo bay pressure. Several points on the curve in

Figure 4.2.5.1-4 were chosen to investigate the influence of cargo bay pressure and it was found that a constant hydrogen leakage would expand to maximum concentration at 2 mm Hg, where reactions are first possible. As a consequence the single most hazardous time in the re-entry flight profile is that time at which cargo bay pressure reaches 2 mm Hg, and less hazardous before and after that time, as far as leakage is concerned.

Using simple pressure-volume relations, with constant temperature, the leaking hydrogen will expand 760/2 or 380 times. The above leakage then expands to 380 times 0.25 or 95 cfh. From Figure 4.2.5.1-4 the orbiter pressure reaches 2 mm Hg in 2400 seconds or 2400/3600 hours, or a total leakage volume of 63 cu. ft. 63/16700 gives a concentration of 0.0038 or 0.38% which is less than 1/10 of the hazardous concentration.

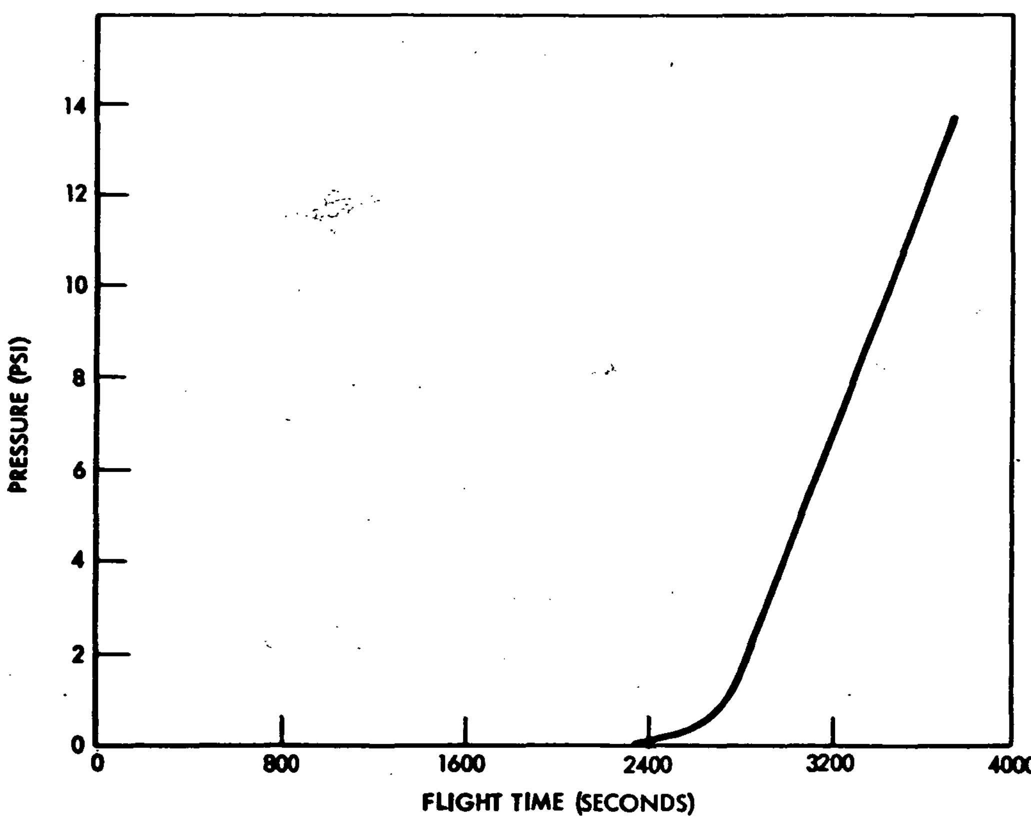


Figure 4.2.5.1-4 Cargo Bay Internal Pressure Time History During Re-Entry

As more precise information becomes available on (1) the free cargo bay volume, (2) the exact configuration of the cargo and its leakage, and (3) better methods to determine how much hydrogen remains in the cargo bay, the curve shown in Figure 4.2.5.1-3 would be useful. This curve relates the total accumulated leakage to the free volume to arrive at a 4% hydrogen curve. The area above the curve would have greater than 4% H_2 and be hazardous and the area below would contain less than 4% and be safe.

4.2.5.2 Technical Discussion - Percentage Hydrogen in Hydrogen Tank Pressurant

The foregoing discussion addressed itself to leaking hydrogen gas from many sources. This gas leaking at the "normal" rate (that rate allowed by specification) could be 100% hydrogen and not reach hazardous concentrations.

If a failure is assumed on the tug when in the cargo bay after the shuttle has committed to re-enter and a "blowing" leak develops the leakage assumes a different character. Any leak from a point source will release the gas in jet form. See Figure 4.2.5.2-1. This jet will interface with the atmosphere and at some point along this interface a reaction can occur if the percentage of hydrogen in the interface is 4% or greater. Reference 11 pointed out that hydrogen-oxygen reactions could occur when the percentage of oxygen in the mixed gases was 2% or greater.

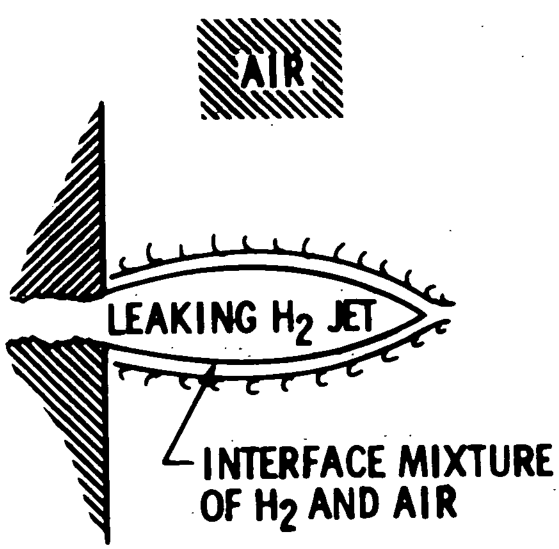


Figure 4.2.5.2-1 A Blowing Leak of LH_2 into Cargo Bay

Since the oxygen source in the cargo bay will be the atmosphere and since air is approximately 20% or 1/5 oxygen the interface mixture must contain a minimum of 2%/1/5 or 10% air to provide enough oxygen to support a reaction. As a result 90% of the gas in the jet must contain enough hydrogen to bring the concentration of hydrogen to 4% in the interface mixture to permit a reaction. Therefore, the maximum allowable concentration of hydrogen in a blowing leak is 4%/90% or 4.5%. The gases escaping from a blowing leak will be diluted by the entrained air that provides the oxygen for a reaction and these gases must contain more than 4% hydrogen (see Figure 4.2.5.2-1).

Since the leakage to be expected from components that are operating within specification is not hazardous, blowing leaks that are hazardous would be caused by a failure. If it is decided to protect the shuttle against these failures by inerting the hydrogen tank the hydrogen concentration must be $\leq$4.5%.

4.2.5.3 Technical Discussion - Detection of Blowing Leaks

As shown in the discussion of the percentage hydrogen allowable in the gases leaking from the hydrogen tank, blowing leaks could be hazardous to the shuttle and crew. It is evident that a means must be devised to detect the presence of blowing leaks.

In most cases the returning element will have completed its mission, the propellants will be largely depleted, the pressure in gas containers will have been greatly reduced and flight stress imposed by thrust and maneuvers will be absent. Its job is done and the evaluation of that job as well as the examination of the physical condition of the element prior to placing it in the cargo bay will determine whether it has been, or is leaking.

Engine performance data, propellant and pressurant utilization data will assist in determining whether gross leakage was present during previous operations of the element. As the temperature stabilizes and the element warms up to reach steady state conditions the likelihood of leakage decreases.

The second and probably the most important leak check that can be made prior to placing the element in the cargo bay is a visual check of the hydrogen systems. As demonstrated on Apollo 9, blowing leaks are highly visible. On this flight the S-IVB performed a second, unscheduled, vent of the propellant tank when it was approximately 100,000 km from the earth, on its way to the sun (Reference 2A). This vent was observed and photographed from the earth as shown on Apollo 9. Any blowing leak would rapidly condense the leaking fluids into clouds of "ice" crystals that would be readily visible during a pre-emplacement visual examination that should be conducted of the returning element.

During rendezvous, docking and emplacement of the element into the cargo bay the element will be under the visual control of the orbiter crew. If the element has been damaged such that it would leak, the crew will know it and should defer the deorbit of the element.

After the element is in place in the cargo bay and the element/orbiter interface connection has been made the third type of leak check should be made. The critical interface connection must be verified to be leak free. A commonly used technique is to run a pressure decay check. The interface connection is isolated, pressurized and the pressure monitored. If the pressure decays the interface is leaking. If the leakage exceeds the allowable rate corrective action must be taken prior to committing to re-enter to prevent hydrogen leakage into the cargo bay.

After the interface has been determined to be leak-free the propellants should be dumped if this operation has not been performed outside the cargo bay. The objective of the propellant dump would be to eliminate as much of the residual liquid propellants as possible.

After propellant dump other pressure decay tests can be run to pick up gross leakage. In the case of the point-design tug, the hydrogen tank contains 1904 cu. ft. Assume that a decay test has been performed and that the pressure had decayed from 17 psia to 16.9 psia (such a pressure differential is well within the state-of-the-art). Using simple PV relationships and constant temperature:

$$P_1 V_1 = P_2 V_2$$

$$17 \times 1904 = 16.9 \times V_2 = 1915$$

Since $V_2 = 1915$, 1915-1904 = 11 cu. ft. of gas at 17 psia would have leaked out, or:

$$11 \times \frac{17}{14.7} = 12.7 \text{ scf of leaking gas}$$

If it is further assumed that the period over which this leakage occurred was the same as the time required to reach the altitude where the cargo bay pressure is 2 mm Hg, then Figure 4.2.5.1-3 can be used to determine the permissible hydrogen concentration in the leaking gas. From Figure 4.2.5.1-3 it can be seen that approximately 1.75 scf of hydrogen will produce a 4% of hazardous concentration in the cargo bay with the tug in place. Then the allowable percentage of hydrogen in the tug tank is:

$$\frac{1.75}{12.7} = .138 = 13.8\%$$

Or, stated another way, if a pressure decay test shows that the hydrogen tank decays 0.1 psia in 40 minutes or less and the percentage of hydrogen in the tank is 13.8% or more the orbiter and crew would be exposed to fire and explosion hazards on re-entry.

The above example assumed that the temperature was constant. If the temperature varies, PV/T relationships could be used in the decay test. It is doubtful that a valid decay test could be run if any liquid hydrogen remained in the hydrogen tank, since the liquid would tend to vary the tank pressure.

4.2.5.4 Hydrogen Leakage Into Orbiter Cargo Bay - Conclusions

Several conclusions can be drawn from this analysis of hydrogen leakage into the cargo bay of the shuttle on re-entry. They are re-stated here in summary:

a. Liquid propellants should be dumped from propellant logistics elements prior to re-entry.

b. Propellant logistics elements should be visually checked for leakage prior to emplacement in the shuttle cargo bay.

c. Normal leakage within specification limits is safe for re-entry, for any concentration of hydrogen in the leaking gases.

d. Blowing leaks into the cargo bay are hazardous, if the concentration of hydrogen in the leaking gases is $\geq$4.5%.

e. Blowing leaks are detectible by existing procedures.

f. The free volume of the cargo bay should be made as large as structural requirements permit by the elimination of unnecessary compartmentation.

g. The shuttle orbiter should be provided with a closed vent and/or dump system that will make a leak-tight interface with the propellant logistics element and terminate in the ambient atmosphere.

4.2.6 Sublimation of Solidified Propellants

During the System Safety analysis the hazard was identified of solidified propellants impinging upon cargo bay surfaces and remaining there to cause fire/explosion during re-entry. The preventive measures that were developed included the requirement to visually inspect the interior surfaces of the cargo bay prior to emplacing a returning module. When solidified propellants were found a further restriction was placed on the orbiter to defer re-entry until the solidified propellants had sublimed.

Further analysis was conducted to determine the length of time that might be required for this sublimation. Reference 2A has projected estimates for the lifetime of individual "ice" particles in free space that would not be directly applicable to the case under consideration. Individual "ice" particles could accumulate in loose form, similar to a snow bank on cargo bay doors, walls and floor. The amount of this accumulation would be dependent on the proximity and severity of the leak as related to the cargo bay surfaces. One of the primary means that could be used to dissipate this "ice" would be to add heat. Since the cargo bay doors have the radiators attached that are used to dissipate the heat generated within the sources, the doors will be warmer and not be governing for "ice" sublimation.

Another likely source of heat that could be used to sublime the "ice" would be the solar thermal flux. If the shuttle was oriented toward the sun with the cargo bay doors open and the only heat source considered being the solar flux, 442.4 btu per hour, will fall on each square foot of the cargo bay (Reference 8A). If the solar heat flux is considered to be absorbed and re-radiated within the cargo bay then this heat would sublime any "ice" present within the cargo bay. The heat of vaporization of solidified H_2 is 239.6 btu/lb. (Reference 21) and 442.4/239.6 = 1.85# of hydrogen would be sublimed from each square foot of cargo bay plan area or approximately 15 x 60 x 1.85 = 1660#/hr from the whole cargo bay.

The maximum, practical, amount of liquid hydrogen that can be carried on one shuttle flight is 28,500 lbs. in a module designed to carry LH_2 only. To choose a worst case example, assume that such a module is being deployed from the cargo bay and the hydrogen tank ruptures a weld when 1/2 tank diameter from the cargo bay. See Figure 4.2.6-1. The liquid will expand, characteristically, 180 degrees and quickly freeze into solid particles. Approximately 15% of the liquid will vaporize to solidify the remaining 85% (Reference 12). Graphically, it can be determined that the included angle through which solid particles could re-enter the cargo bay is approximately 50°.

Therefore:

$\frac{50}{180}$ x 28,500 lb. x .85 = 6730 lb. of solidified hydrogen is the maximum amount, under worst case conditions, that could be deposited in the cargo bay. In actual practice, if such an incident did occur and a hydrogen tank dumped its whole load into the cargo bay much of it would blow out because of the velocity of the expanding gaseous hydrogen.

If it is assumed that 50% of the solids formed remained in the cargo bay,

$$\frac{6730 \times .50}{1660} = 2 \text{ hours} = \text{sublimation time}$$

Under worst case conditions the orbiter would have to be oriented toward the sun for at least two hours to sublime solidified hydrogen.

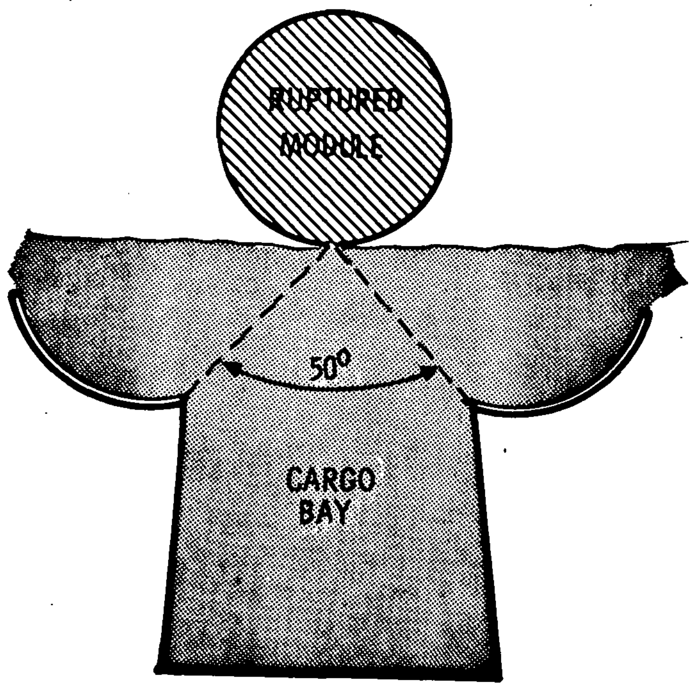


Figure 4.2.6-1 Solidified Propellants in the Cargo Bay

4.2.7 Abort Considerations

Any discussion of the requirements imposed on a propellant logistics element during abort conditions must begin with the shuttle. During the SD shuttle studies the conditions that exist during abort have been studied for each configuration of orbiter and booster. The time available to perform critical functions during abort is determined by several factors. These factors include the configuration of the booster, orbiter and orbiter payload and the mission requirements including orbital inclination. As a result of the large number of possible combinations, the available time cannot be fixed but presented as maximum and minimum.

4.2.7.1 Landing Safety Relative to Payload Weight

In general, the orbiter is restricted to landing with a 40,000-pound payload with an optimum degree of safety and with larger payloads with a reduced factor of safety. As a result any propellant logistics element must be limited to a landing weight of 40K to introduce minimum risk to the orbiter and crew.

4.2.7.2 Shuttle Abort Regimes

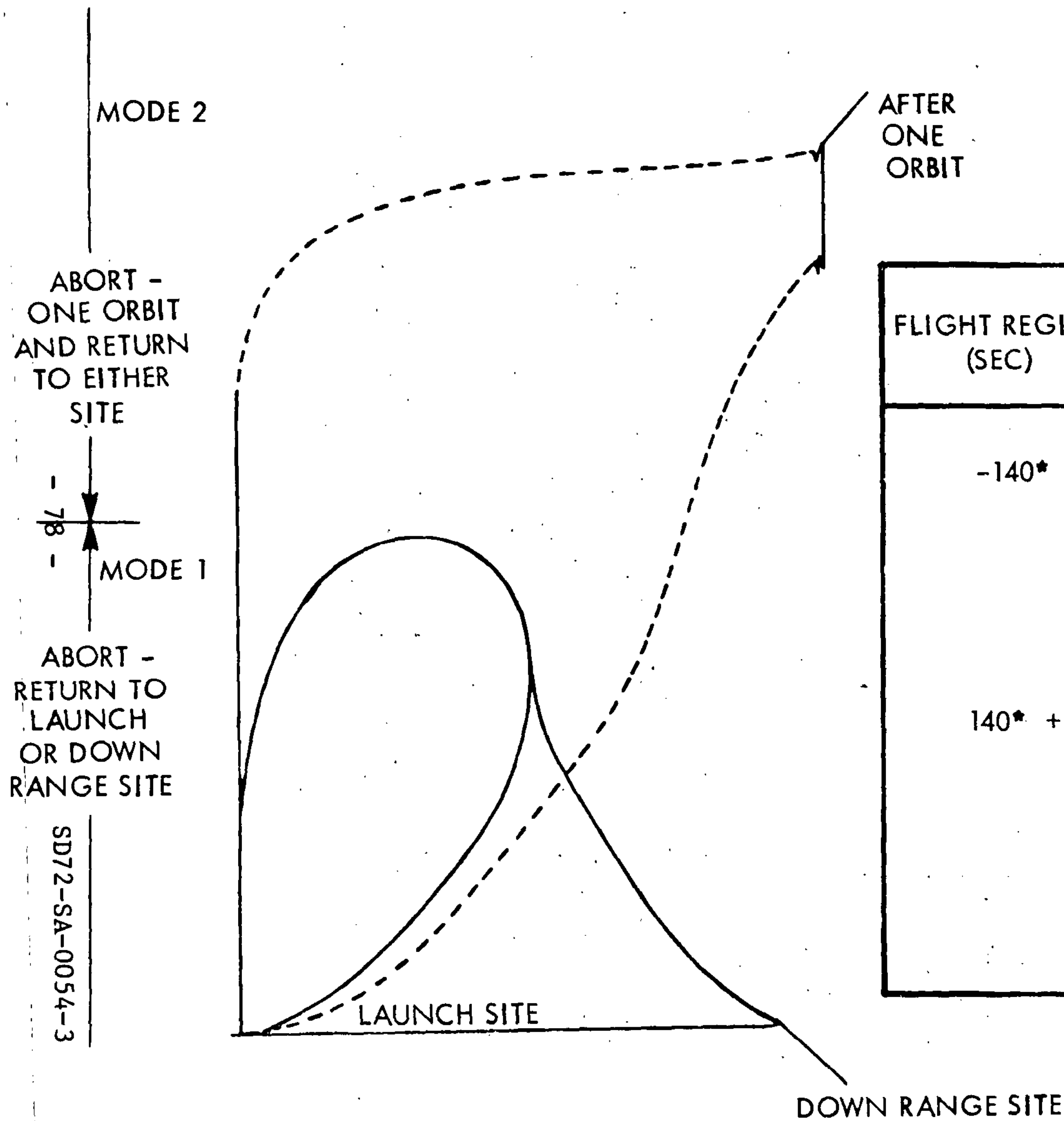
The above-mentioned combinations can be divided into four shuttle abort regimes. The first would occur from liftoff (T-0) until 20-30 seconds after liftoff when the booster has not imparted sufficient velocity to the orbiter to permit independent orbiter flight. During this period the orbiter will achieve independent flight capability with thrust augmentation by add-on capability such as solid rocket motors. The second orbiter abort regime occurs after the first and before booster-orbiter staging when the orbiter has independent flight capability and elects to land at the launch pad. The third regime is the same as the second with the landing site being an alternate. The first three orbiter abort regimes can be discussed as a single abort mode for a propellant logistics element carried as cargo. The period during the 200 to 300-second orbiter flight to the landing site is the time that must be utilized to dump propellants, as necessary, to lighten the orbiter payload to meet the 40K landing limitation. Because of certain near-vertical orbiter flight attitudes and propellants lingering near the orbiter it would not be advisable to dump both LOX and LH_2 simultaneously. The accelerated combustion of the hydrogen in this case could be hazardous to the orbiter. The two abort modes are summarized in Figure 4.2.7.2-1.

4.2.7.3 Payload Propellants Dump

If the propellant logistics element in the orbiter cargo bay contained both LOX and LH_2 (such as a tug or Centaur) or contained LOX only (such as a LOX module), the least hazardous propellant dumping mode would be to dump the LOX. Because of the greater density of LOX over LH_2 fewer cubic feet of LOX would have to be dumped to achieve the required weight reduction. As a result the dump line would be smaller and lighter.

When the propellant logistics element in the cargo bay, or external to the cargo bay, contains LH_2 only, the requirement to lighten the orbiter payload would become the driver in establishing the orbiter flight profile and attitude. When dumping LH_2 in the atmosphere, the objective should be to expose the orbiter and crew to the minimum risk from the trailing cloud of hydrogen. The lines would have to be sized to permit dumping the necessary amount of LH_2 in the time (200 seconds, worst case) and under orbiter flight attitudes optimum to dumping LH_2. Design attention must be given to the dump line exits, its placement on the orbiter, and the need for the isolation of atmosphere and hydrogen to prevent the back diffusion of oxygen into the LH_2 dump line.

After staging the orbiter has once-around abort capability, even though a failure would prohibit the vehicle from achieving final orbit. The orbiter flight time during this fourth abort regime is approximately 100 minutes which would provide adequate time to dump propellants and prepare the propellant logistic element for a landing.



* APPROX STAGING TIME

MODE 1 - BOOSTER FAILURE - 200-300 ORBITER FLIGHT TIME - DUMP LOX

MODE 3 - ORBITER FAILURE - ONE ONCE AROUND ORBIT CAP - DUMP & SAFE TUG TANKS

FLIGHT REGIME (SEC)	FLIGHT TIME TO LAND (SEC)	PROPELLANT DUMP ABILITY	SAFETY CONSIDERATIONS
-140*	200-300	• LOX CAN BE DUMPED • LH_2 WILL BE KEPT ON BOARD	• DUMP LOX • SAFETY HAZARD WITH LH_2 DUMP IN ATMOSPHERE
140* +	6000	• BOTH LOX AND LH_2 CAN BE DUMPED (TIME REQ'D TO DUMP BOTH 27 MINS)	• SAFEST ABORT POSSIBLE

Figure 4.2.7.2-1 Abort Envelope

4.2.8 Propulsive Effect of Venting or Leaking Fluids

The propulsive effect of vented or exhausted fluids from propellant logistics elements, or the propulsive effect of credible leaks is one of the factors that must be considered in designing the stabilization systems of the element.

The design process must include the sizing and placement of vents and exhaust outlets and the trade-offs must be performed necessary to establish whether the outlets are to be propulsive, non-propulsive or both (on command). Since the elements that would contribute to this decision-making process are established, they will not be addressed here.

The assumptions that must be made to establish the propulsive effect of credible leaks would include the size or magnitude of the leak involved. One possible source of sudden leaks would be holes caused by the impact of hyper-velocity meteorites. It has become a practice to use the impact of a meteoroid of one gram mass as a design point. The impact of a meteoroid of this size would produce a hole of approximately 2" diameter in typical tank walls and this can be used as the size of credible leaks.

After simplifying assumptions, the following approximates the thrust from leaking fluids.

$F = PA$, for gases
$F = 2\ PA$, for liquids
where F = thrust in pounds
P = pressure in psia, assume 32 psia
A = area of hole

therefore: $F = 32.2^2 \frac{\pi}{4} \simeq \underline{100\text{ lb.}}$ for gases
$= 2\text{x}32.2^2 \frac{\pi}{4} \simeq \underline{200\text{ lb.}}$ for liquids

As shown, the propulsive effect of leaking gases can be a significant factor in its contribution to the vehicle dynamics. When this force is applied through the center of gravity its effect is simple translation of the leaking assembly. This would be a consideration in the impact of two adjacent vehicles when the force is not directed through the CG, but at considerable distance from the CG, the effect will be to induce rotation of the assembly. This rotation could have adverse effect in impacting vehicles that are close together or in accelerating or decelerating rotation.

4.3 DESIGN INFLUENCES OF HAZARD ANALYSIS

The System Safety study has identified hazards within the representative orbital propellant logistic operations which may have an influence on the design of space logistic systems. These are identified in the following paragraphs.

4.3.1 Attach Points in the Cargo Bay

The use of line interconnect fixtures for line connection interfaces with the cargo bay will most likely be located at a fixed station. During the design concept phase, the number of logistics elements to be connected at this interface should be considered for location of the airborne half of the line interconnect fixture. These fixtures will be indexed by the location of the attach points on the orbiter and logistic element. Safety during retrieval operations requires attach points to be such as to assure the fixtures can be mated upon return of the logistic element into the cargo bay. This problem is accentuated by the different module and logistic element lengths, CG location and location of anticipated payloads.

4.3.2 Capability to Determine Residual Propellants Quantity

The capability to know what quantity of residual propellants are in the logistic elements' tanks is required to ascertain that it is safe to return to earth in the cargo bay of the orbiter. The logistic element will be returned to the cargo bay and all vents will be connected to a vent system, venting overboard from the orbiter. The propellants within the logistic elements' tanks must be dumped overboard and the tanks checked for leakage within specification after dumping excess propellants. The residual propellants could be the source for tank overpressurization; if due to insulation failure, heat is transferred into the tank structure. With sloshing of the propellants, the propellants will instantly gas off causing increase in ullage pressure. Should excessive amounts of residuals remain, gassing off in this manner, the vent valve may not be able to react to the pressure buildup, causing tank rupture. Thus, only a quantity of residuals which will not overpressurize the tank under re-entry conditions described above will be allowed to remain in the tanks. The capability to determine these quantities accurately will present an impact on design of the system.

4.3.3 Emergency Propellant Offloading on the Pad

The position of stowage in the orbiter cargo bay may or may not be in the engine down mode for loading. From a system safety standpoint all logistic elements in the cargo must be capable of gravity feed off loading under emergency conditions.

4.3.4 Disturbance Coupling with Configuration Dynamics

The effect of sloshing, fluid surface distortion, CG control, potential mass spills, intermittent RCS operation or uncontrolled venting upon the dynamics of the docked configuration is required to determine the conditions the elements will be subjected to during orbital operations. The outcome of the effects will impact design considerations of each element expected to be used in an integrated configuration.

4.3.5 Dumping of Propellants for Abort Operation

In order to make a successful orbiter weight for landing, propellants from the propellant logistic element in the cargo bay will have to be off loaded. This off load will have to be accomplished within 200 seconds, which is the minimum time from a decision to abort, to landing.

Since the propellant logistic elements weigh as much as #65,000, under present estimate at least 25,000 lbs. of propellants must be dumped within the 200-second period for attaining an allowable loading weight. This dump requirement will impact the orbiter design consideration for carrying propellant logistics elements within the cargo bay.

the identified hazards encompassing the representative orbital propellant logistic operations when used with the conditions contributing to the hazard, provide the basis for development of specific preventive measures.

5.0 PREVENTIVE MEASURES

The objective of preventive measures was to reduce catastrophic and critical hazards to the level of at least marginal and preferably negligible. As each hazard was identified on the Hazard Analysis sheet, the steps to be taken to reduce the hazard to an acceptable level were detailed in the "Action Recommended" blank. This "Action Recommended" then becomes the preventive measures.

The application of preventive measures that have been successful in reducing similar hazards on past programs were successful in reducing hazards in propellant logistics operations in the majority of cases. Thirty-three hazards were not successfully reduced below the critical level. These residual hazards have been identified in this section and Appendix D. Continued effort must be placed on the reduction of these residuals. Some advancement in technology is required to reduce some hazards. This technology advancement is identified in this and other sections of this volume.

The necessity for an operations monitor has been identified as well as the monitoring devices that should be incorporated to provide the monitor with necessary data.

5.1 HAZARD REDUCTION PRECEDENCE SEQUENCE

The action recommended covers one or more recommended means to eliminate or reduce the hazard. If the hazard cannot practically be eliminated the actions for reducing the hazard in order of precedence are those contained in OMSF Safety Program Directive No. 1, Revision A, condensed here for the convenience of the reader.

a. Design for minimum hazard.

b. Use appropriate safety devices.

c. Provide devices for timely detection of the condition and generation of adequate warning signals.

d. Develop special procedures to counter the hazardous condition and enhance personnel safety.

e. Residual hazards shall be those for which none of the above actions are effective in counteracting the hazard and shall be justified and documented.

5.2 PREVENTIVE MEASURES FOR IN SPACE PROPELLANT LOGISTICS SAFETY CRITICAL OPERATIONS

Preventive measures were developed for the safety critical operations that would be performed during deployment, docking, transfer and retrieval. These operations were treated in detail in Appendix D but some of the most significant ones will be discussed here.

5.2.1 Deployment

The operations conducted during deployment are largely manual operations. The variables introduced by the human element are compounded by variables brought on by the different operating modes of the vehicles being deployed and by the limitations of the equipment visualized as being used in the deployment process.

The deployment process consists of all those steps necessary to remove an element from the cargo bay of the orbiter, translating it away from the orbiter by rotational means or on the slender, flexible arms of the manipulators or both, and preparing the element for the next step, docking or release.

When the element is first released from its interface with the orbiter, the latches that are provided to hold the element in the cargo bay may bind up or not fully release. The preventive measure for this occurrence would be the provision of backup release mechanisms.

When partially out of the cargo bay, uncoordinated movement of the manipulator arms may cause fluid sloshing to be set up that would impact the element and cargo bay walls. The preventive measure for this hazard would be the provision of slosh dampening devices that would dampen out this oscillation before it reached hazardous proportions.

Any time the element is extended on the slender manipulator arms (60 feet long) propulsive venting of the propellant tanks would introduce moments into the system that would produce tumbling. If the RCS System of the orbiter tended to correct the rotation the manipulator arms would be bent or curved to store up energy that would be released when the venting stopped. This could set up oscillatory motion until dampened out. The preventive measure for this hazard would be the procedural operation of locking out the vent valve of the element to prevent venting during this phase. The tank pressure would continue to build up by gas pressure from heat leaks and would require monitoring the tank pressure to be sure it did not reach hazardous levels until it could be safely vented. An additional hazard of this nature is the propulsive effect of leaking fluids. Any incident that would lead to sudden leakage of significant volume (a 2" diameter hole) would remain a residual hazard.

The hazard of venting fluids would be compounded by the visual restrictions that would occur when "ice" particles from the venting fluids obscured view ports, TV lenses or other visual aids. Retractable shields to protect the visual aids would be the preventive measure for this hazard.

5.2.2 Docking

The docking process consists of all those operations necessary to join two independent orbiting units into one, interdependent unit. Docking can be broken into two broad classifications, hard and soft.

Soft docking is done with the assistance of the manipulators in the orbiter cargo bay. Soft docking begins with the orbiter station keeping in close proximity with another vehicle that is to receive the element from the shuttle cargo bay. The element will have been deployed and remain attached to one or both of the manipulator arms. At this point one of the manipulator arms can be attached to the receiving vehicle to maintain a fixed relationship between the orbiter and receiving vehicle, or the orbiter and receiver can retain free-flying attitudes and both manipulator arms used to bring the active and passive docking elements into initial contact.

Hard docking is performed without the assistance of the manipulators. The active element makes the initial contact - docking port to docking port - without intermediate assistance.

After initial contact is made by hard or soft docking the remainder of the steps in the docking process are the same. These consist of making the capture, rigidizing the interface and completing the interface connections to, in effect, join the two vehicles into one in preparation for subsequent operations. The hazards and preventive measures that relate to vehicle stability during the docking operations are similar to the same hazards that would occur during deployment and are discussed there.

The docking approach angle and velocity is critical to the success of the docking operation. Docking mechanisms must be designed to accept contact within small angular deviations from the docking axis. For this reason the two vehicles must be stable with relation to the other and the docking axis aligned within a typical 5 degrees. Attempts to dock when the angular deviation is excessive could result in one or more capture latches failing to capture and lead to problems when separation is attempted for another try. Excessive closing velocity would exceed the capability of the shock attenuation system and cause structural damage on impact. Procedural controls and crew training would be the preventive measures in the manual case and redundancy in the automatic case.

During the docking approach anything that would tend to introduce deviations in the approach could lead to collision damage. These would include fluid sloshing introduced by unstable manipulator operation, the propulsive effects of venting fluids and the propulsive effects of credible leaks. When the two vehicles are being joined the two RCS systems should be integrated so they act as one unit. If both RCS's remain independent they would likely produce opposing thrust that would lead to "working" at the interface, possible structural damage or rapid depletion of RCS propellants. The preventive measure for this hazard would be to integrate the two RCS's on docking.

The hazard of large amounts of momentum energy being translated into fluid movement during docking could be dampened out by baffles. The contribution of this momentum to further vehicle instability should be more fully investigated.

After the two vehicles are joined the interface connections, mechanical, fluid and electrical should be verified to make sure they are valid prior to beginning subsequent operations.

For a more detailed treatment of docking preventive measures, see Appendix D.

5.2.3 Propellant Transfer

Propellant transfer, as used in this section, consists of those operations necessary to translate fluid propellants from one tank into another.

After the two vehicles, the supplier and the user, are joined and the interface connections have been verified the propellant transfer operations can begin. Liquid/vapor interface control is accomplished by settling the propellants by applying gravity induced by acceleration or by the use of passive (capillary) devices. Acceleration can be applied by inducing rotation to the assembly or by applying thrust in a linear fashion. When accelerating the assembly a manned element (orbiter) may or may not be attached.

Because of the small acceleration forces involved the transfer period is shortened to 10 hours by pumping the fluids in conventional fashion.

The hazards encountered, to which preventive measures must be applied, are those that would affect the stability of the vehicles, maintaining the transfer for extended periods of time, thermal effects on the user and behavior of propellants in zero "G." For a detailed discussion of the preventive measures to be applied to the hazards involved during propellant transfer, refer to Appendix D.

5.2.4 Retrieval

Essentially the retrieval operation includes the same hazards introduced during the deployment operation, in reverse order, with the additional hazards attendant to the deorbit of the shuttle.

In the preparations for deorbit and the deorbit phase itself, hydrogen leakage into the cargo bay would be a major hazard. Prior to retrieval the spend module should be visually examined as a preventive measure for leakage either by TV on the manipulator arms or from the view port while rolling the orbiter around the module or rotating the module in view of the crew. Leaking fluids will be highly visible and a leaking module should not be returned by the shuttle until corrective action can be taken. If no leaks are visible and no solidified propellants are visible on the module or in the cargo bay and the propellant utilization history of the module does not indicate high losses the module may be retrieved by the manipulators and placed in the cargo bay. At this time the hookup of the module should be completed and to guard

against the hazard of propellants leaking directly into the cargo bay, the preventive measure should be taken of leak checking the interface connection between the vent/dump lines of the module and orbiter. When it has been determined that this connection is leak free the residual liquids should be dumped from the module. Propellant dumping could be performed before retrieval but if it is to occur during the retrieval cycle it should not be performed until the interface connection has been leak checked as a preventive measure to guard against the hazard of solidified propellants being deposited and deorbiting in the cargo bay. After completion of propellant dump the entire hydrogen system of the module should be leak checked. If the module is not leaking out of specification, normal leakage will not be hazardous to the orbiter or crew on re-entry.

5.3 MONITORING DEVICES

Providing propellants to a user in space is a complex operation and could be made fully automatic. For operations that are repeated many times and to minimize human error, a preventive measure was recommended that the repetitive operation be automated.

Even though propellant logistics could be automated, manned elements (shuttle orbiter) will be used as a delivery element. The introduction of the manned element requires the addition of another, the Operations Monitor.

To fulfill the requirements of being aware of the progress of orbital events would necessitate the provision of monitoring devices that would include the following:

a. Electrical Power
b. Pneumatic Supply
c. Valve Position Indicators
d. Propellant Tank Pressure and Temperature
e. Propellant Gauging
f. Operating Cycles
g. Leak Check
h. Line Interconnect Fixture Verification
i. Docking Latches
j. Redundant Systems Status
k. Hazardous Gas Detectors
l. Fire Detectors
m. LSS Operational Levels
n. Space Debris Warning

For a detailed discussion of these monitoring devices refer to Appendix D.

5.4 RESIDUAL HAZARDS

Catastrophic and critical hazards encountered in propellant logistics operations were identified and analyzed. The objective of preventive measures was to reduce these hazards to at least marginal and preferably negligible. After the application of the preventive measures if the hazard still remained

at a catastrophic or critical level then the hazard is residual.

Thirty-three remained as residuals. These include:

a. Meteoroid Impact
b. EVA Operations
c. Propellant Quantity
d. Disturbances
e. Propellants Venting into Cargo Bay
f. Deorbit
g. Docking Between Unstable Vehicles
h. Manual Docking Operations
i. Reduction of Vision

For a detailed discussion of these and other residual hazards refer to Appendix D. Continued emphasis should be placed on the reduction of these residuals. As the configuration of the hardware and the operation of this hardware approaches maturity, available technology and study should continue to be applied to hazard reduction.

5.5 CONCLUSIONS

During the course of this study it was found that preventive measures that had been used on past programs could be used to reduce hazard potential for propellant logistics operations in the majority of cases. The application of these preventive measures did not reduce the hazard potential to an acceptable level in 33 cases. The development of future, similar programs should include the application of these preventive measures and continued emphasis on the reduction of the residual hazards. In certain cases (propellant gauging, for example) it was found that advancement in the state-of-the-art was necessary to develop preventive measures.

The requirement for an Operations Monitor was established, even though propellant logistics is fully automatic. Some of the data that must be provided to the Operations Monitor was defined. As the design of propellant logistics hardware proceeds continued study should be applied to the definition of additional monitoring devices that would be required.

6.0 TRADE STUDIES

In the Representative Orbital Propellant Logistic System baseline operations with variations, it becomes evident the viable options for accomplishing certain operations would require evaluation for determining the hazards involved with the option and the safest conceptual approach. This section includes safety evaluations for rotational and manipulator deployment mechanisms which involve hard and soft docking respectively, Options of the Orbiter attached or not attached during fluid transfer, and tug, CIS/RNS, modular element, and orbiter to orbiter options for delivery of propellants direct to a user.

The deployment mechanism, Orbiter attached or not attached, and orbiter to orbiter evaluations were made using safety considerations applicable to the specific evaluation, while the various space element (Tug, CIS, Modular) options for propellant transfer were evaluated against a common set of safety considerations. These safety considerations are as follows.

a. Number of Critical Operations

   This evaluates the critical operations covering the orbital operations from the time the orbiter arrives with the propellant tank module through deployment, docking, transfer and retrieval.

b. Number of Failure Effects

   1. On the Crew

      This item evaluates the major potential hazards to the crew as a result of the affects of a failure during deployment, docking, transfer and retrieval.

   2. On the Structure

      This item evaluates the major potential hazards to the structure as a result of the affects of a failure during critical operation.

c. Crew Exposure to Risks During Normal Operations

   This evaluation item covers the risks associated with a time line during which the propellant logistic elements are engaged in fluid transfer.

d. Attitude Control Capability of Total Configuration

   This evaluation item covers those aspects of the configuration dealing with control of disturbances, structural interaction and RCS operation.

e. Impact Control

This evaluation item covers those operations during deployment, docking, transfer and retrieval which are directly relatable to potential impact conditions.

f. **Man-Compatibility**

1. Logistic Element (Tug, CIS/RNS, Modular)

This evaluation item covers the requirements, or lack thereof, of man-rating of the element as it relates to its functioning in relation to the orbiter.

2. Propellant Tank Module

This evaluation item covers the requirements, or lack thereof, of man-rating of the tank module as it relates to its functioning in relation to the orbiter.

g. Communication Control

This item evaluates the continuity of maintaining communications in the operational mode during transfer.

h. Leakage Control

This evaluation item covers the major factors contributing to leakage, by configuration.

The deployment mechanism evaluations indicated each type of option had advantages relating to specific operations while a combination of both was best for certain operations. As an example the rotational deployment provides more control of clearances between the propellant tank module and the cargo bay walls than the manipulator, while the manipulator provides less impact potential with the passive vehicle because of less impact velocity. The combination of both is best when the propellant tank module is soft docked to another logistic element.

The orbiter attached or not attached safety evaluation indicated greater safety is required with the orbiter attached, however, if all mated configurations are man-rated the choice reduces to the commitment time of the crew for the operation.

The trade study for four viable tug transfer concepts concluded the safety preferred concept was non-deployment of the propellant tank module with rotational acceleration for propellant settling. The tug is soft docked to the propellant tank module. This selection had the advantage of reducing the number of critical operations in the cargo bay. A close second preference was the concept where the tank module is deployed and docked to the tug and then the fluid transfer is accomplished in a

separated mode using linear acceleration for propellant settling.

The safety trade for four CIS/RNS transfer concepts concluded the preferred propellant transfer mode was with the CIS/RNS and module attached and linearly accelerated for transfer.

Safety evaluation of a conceptual modular concept of the CIS/RNS type indicated it to be competitive with the non-modular approach.

Of the three orbiter to orbiter transfer concepts evaluated, no safety preference could be defined. As the configuration reaches maturity additional trades should be conducted.

A detailed discussion is contained in the following paragraphs.

6.1 INTRODUCTION

Safety evaluations were made of two deployment mechanisms, two modes of operation for propellant transfer, four tug concepts, four CIS/RNS concepts, one modular concept, and three orbiter to orbiter propellant transfer concepts.

6.1.1 Evaluation of Deployment Mechanisms

During the safety study, evaluation of deployment mechanisms was made to support the analysis of operations in which the deployment mechanisms were involved. This evaluation provided insight into operations where use of the manipulators provided better concept from the safety standpoint, and those operations where a rotational deployment mechanism provided greater safety. See Section 6.2 for evaluation of deployment mechanisms.

6.1.2 Orbiter Attached Vs. Orbiter Not Attached for Propellant Transfer

With the variations to the representative orbital propellant logistic operations, which introduced propellant direct supply to the user, the orbiter became involved in the fluid transfer process. With the potential use of rotational or linear acceleration for propellant settling, the orbiter may be either attached during the process or not attached. A safety evaluation was thus made on these two possible modes of operation of the orbiter. The evaluation is contained in Section 6.3.

6.1.3 Tug Concepts

The above evaluations were used along with the conditions contributing to hazards identified for the propellant transfer operations, in performing a safety trade study on four tug transfer concepts considered candidates for the case of orbiter direct to user propellant transfer. The trade study is contained in Section 6.4 with rationale and preferred configuration. This trade study was made on a safety basis and selection was independent of programmatic or engineering considerations.

6.1.4 CIS/RNS Concepts

The same type of trade study as that for the tug concept was done for the CIS/RNS concept. In these, **four CIS/RNS configurations were candidates** for evaluation from a safety viewpoint. For convenience these were called Concepts A, B, C and D. Concepts A and B involved rotational acceleration for propellant settling with "A" having no orbiter attached while "B" had the orbiter attached. Both concepts A and B have CG's falling within the CIS/RNS tankage. This consideration was a factor in deciding to discard concept A from the trade since concept B included hazards which when evaluated also would include the conditions of concept A. The trade study is contained in Section 6.5 with rationale and safety preferred selection.

6.1.5 Modular Concept

A single modular concept was evaluated for comparative purposes with the CIS/RNS. The evaluation is contained in Section 6.6. Since only one concept was evaluated no safety preference was made.

6.1.6 Orbiter to Orbiter Concept

One variation to the Representative Orbital propellant logistics operations baseline involved delivery of propellants by the orbiter to another orbiter. This case was evaluated for three different methods of transferring propellants in orbit between orbiter elements, from a safety standpoint only. There was no method selected as preferred from a safety viewpoint as the changes in orbiter configuration and location of the RCS and OMS make selection premature. The evaluation is contained in Section 6.7.

6.2 SAFETY EVALUATION OF MANIPULATOR VS ROTATIONAL DEPLOYMENT MECHANISMS

6.2.1 Introduction

In the propellant logistic operations the Orbiter will have a requirement for deploying a propellant tank module from the cargo bay for docking to a user vehicle. The objective was to evaluate, from a safety viewpoint, two different deployment mechanisms which are viable candidates for use in propellant logistic operations. This evaluation was needed for consideration of hazards associated with orbiter cargo bay operations involving propellant tank module deployment.

6.2.2 Summary of Results

It was concluded from the evaluation that in the propellant logistics operations there is no clear cut overall advantage in one mechanism over the other. Each mechanism has advantages and disadvantages which are directly associated with the specific operation; **e.g., the case where the** impact hazard due to sloshing of propellants during deployment out of the cargo bay is reduced by use of the rotational deployment mechanism where

clearance control is a function of structure (tank) deflection, compared to impact during sloshing as a function of manipulator dynamics and control operations.

Alternatively, the manipulator mechanism use for soft docking affords fewer impact hazards causing major damage when docking at 0.1 feet per second, than hard docking with the rotational mechanism at 1 feet per second.

From a safety standpoint a combination of the two concepts applied to the deployment, docking and retrieval operations would provide greater safety than either individual concept.

6.2.3 Safety Considerations and Evaluation of Manipulator Mechanism vs Rotational Mechanism

The safety considerations used in the evaluation are contained in Table 6.2.3-1. The evaluation considered those conditions relating to propellant logistic operations in orbit and are also included in Table 6.2.3-1.

6.2.4 Rationale for Safety Consideration

The rationale for this evaluation by item is as follows.

a. Item 1 - In removing the propellant tank module from the cargo bay, movement of the fluids (LH_2 LO_2) by erratic operation, RCS thrust, venting, uncontrolled leakage or operation of propulsion vents on the orbiter, could cause sloshing. When suspended on the manipulator with the propellant tank not completely withdrawn from the cargo bay the dynamics of the manipulator could result in problems of maintaining clearance under sloshing conditions.

   For the rotational deployment mechanism, the structural rigidity of the mechanism and load are fixed through the docking mechanism. Sloshing, occurring during tank deployment, is restrained by the tank structure, which should not deflect to the point of impacting the cargo bay walls. The structural rigidity should provide more wall clearance control in this case.

b. Item 2a - In attaching the manipulator to the propellant tank, the operation is done using TV aids and floodlights in making contact with the attachpoint. **Erratic manipulator operations could create an impact with the module.**

   The rotational mechanism is attached to the module during ground operations and thus requires no in-flight connection operations.

SAFETY CONSIDERATIONS FOR
EVALUATING
DEPLOYMENT CONCEPTS

Item	SAFETY CONSIDERATION	MANIPULATOR MECHANISM	ROTATIONAL MECHANISM
1.	Cargo Bay clearance control during removal from cargo bay	Less	More
2.	Damage potential in attachment to propellant module during:		
	a. Deployment	More	Less
	b. Retrieval	Less	More
3.	Docking impact velocity	Less	More
4.	Susceptibility to disturbance	More	Less
5.	Ease of stowing after use	Less	More
6.	Separation of vehicles during docking	More	Less
7.	Control stability with payload extended	Less	More
8.	Stability of configuration CG due to sloshing	Less	More
9.	**Stability in passive vehicle for docking**	Less	More
10.	Control operations for deployment mechanism	More	Less
11.	Depth perception required during deployment and retrieval	More	Less
12.	Potential mechanical failure points	More	Less

Table 6.2.3-1

SAFETY CONSIDERATIONS FOR EVALUATING DEPLOYMENT CONCEPTS (Cont.)

Item	SAFETY CONSIDERATION	MANIPULATOR MECHANISM	ROTATIONAL MECHANISM
13.	Potential for impact		
	a. During deployment from cargo bay	More	Less
	b. With passive vehicle	Less	More
	c. During retrieval and stowing	More	Less
14.	Imparts unscheduled rotation to passive vheicle in missed docking attempt	Less	More
15.	Expected smoothness of operating mechanism	Less	More
16.	Capability to deploy other than logistic element	More	Less
17.	Assistance in EVA and emergencies	More	Less
18.	Rotation hazard of passive vehicle from capture latch not releasing during abortive docking	Less	More
19.	Hazard to Shuttle by angle of docking approach to passive target		
	a. Horizontal	Less	--
	b. Vertical	Less	More
	c. Intermediate angle	Less	More
20.	Damage to logistic element if cargo bay attach fittings do not release and deployment is initiated	Less	More
21.	Susceptibility of Orbiter to impact hazard if jettisoned	More	Less

Table 6.2.3-1 (Cont.)

Item 2b - The retrieval operation requires matching orbit and speed with the passive vehicle and through use of manipulator aids, attaching the manipulator to the module. The potential for impact of the manipulator with the module is present and is a function of manipulator operators skill and orbiter stabilization.

The module must be retrieved by hard dock in the case of the rotational mechanism. On a basis of velocity control and energy involved in the hard dock operation, it is envisioned less damage potential exists with the manipulator operation than that for the rotational mechanism.

c. Item 3 - Because of the energy transfer involved in docking the propellant logistic elements to each other, the lower the approach velocity, the less damage from impact could be expected. The manipulator operates at approximately 0.1 feet/sec. while the hard dock is approximately 1 foot/sec. Thus hard dock to the rotational mechanism would give more impact for the same module.

d. Item 4 - The dynamics of the long manipulator arms with the propellant tank module attached introduces more susceptibility to disturbances of sloshing, RCS, propulsive vent operation or uncontrolled venting than the rotational deployment mechanism plus module because the latter is structurally attached to the orbiter with less deflection potential.

e. Item 5 - The rotational deployment mechanism folds into the cargo bay and the entire structure can be secured with latches at point of final travel. The manipulators must be laid into the volume on either side of the cargo bay. Because of their length and joints, it was considered more difficult than the rotational mechanism stowing.

f. Item 6 - Because of the manipulator length plus length of the extended module, greater separation is provided between the orbiter and passive vehicle than in the rotational device with module attached.

g. Item 7 - This case is a function of the control operators ability and the dynamic response to disturbances. Because of the dynamics involved and moments which are created therewith, the manipulator is considered to afford less control stability than the rotational mechanism.

h. Item 8 - This case involves the movement of fluids within the tank such that a CG excursion can be expected which could be amplified by the dynamics of the manipulator. Those dynamics conditions do not present as great a reaction in the case of the rotational mechanism which provides better stability under sloshing conditions.

i. Item 9 - The manipulator has flexibility in movement such that not as much stability is needed in the passive vehicle, as alignment can be varied by the control operations. Where a passive vehicle is not completely stable, hard docking using the rotational deployment mechanism concept should not be attempted.

j. Item 10 - The rotational deployment mechanism is raised and lowered by actuators without any complicated control device. The manipulators are made up of various segments and joints each capable of performing a particular function. These joints have electrical motors for powering their operation. For redundancy there are two manipulators each having TV cameras and floodlights mounted thereon. The controls for the manipulator functions therefore require more operations for assuring a coordinated deployment and retrieval.

k. Item 11 - For the manipulator operations during deployment the TV aids and direct observations will have to be used. **Depth perception, therefore, becomes a factor in estimating the clearance of the tank from the cargo bay walls, doors, etc. In using the rotational mechanism for deployment or retrieval, depth perception is not a factor.**

l. Item 12 - In the rotational deployment mechanism the potential mechanical failure points are considered to be at the hinge points and at the actuator attach points. This failure could be a result of a hard dock or impact due to misalignment. The manipulators have joints, hinges and rotating points where mechanical failure could occur. These failures could be due to deflection under load or structural failure. The number and complexity of the mechanical systems thus indicates more potential failure points exist in the manipulator.

m. Item 13a - See Item 1.

n. Item 13b - Because of the greater separation distance between active and passive vehicles while using manipulators, there is less potential for impact. An assumption used here was that the passive vehicle would be completely stable and propellant sloshing or other disturbances did not exist at the time of docking preparation and during docking. The assumption applied to use with both deployment mechanisms.

o. Item 13c - Case 1 applies to the clearance problem leading to impact during emplacement in the cargo bay. The stowing by manipulator requires depth perception and coordinated operator action in order to locate the tank properly in the cargo bay attach points. This is considered more difficult and contains more impact potential than the rotational deployment mechanism which by its indexed location, will place the tank into the attach points without requiring any operator depth perception, and

will be controlled by limit switch at latching.

p. Item 14 - Because of the lower docking velocities of the manipulator compared to "hard docking", the impact of a missed docking attempt will have less transfer of energy, than that employing a rotational deployment mechanism in hard docking.

q. Item 15.- The rotational deployment mechanism is expected to have few conditions which preclude smooth operations in an orbital operation. Because of the dynamics of the manipulators under deflection from sloshing conditions or bending joints it has greater potential for erratic operation.

r. Item 16 - The use of manipulators in payload deployment for both large and small payloads, other than logistic elements, or where docking the payload to a delivery element, has greater flexibility of utilization. The close proximity of the orbiter when attempting to hard dock a small payload using the rotational deployment mechanism also increases the potential for impact between the delivery element and orbiter/payload.

s. Item 17 - It is postulated that the manipulator can provide more assistance in EVA's, and emergencies where a module retrieval may lessen the extent of the hazard to crew members or where a crew member doing EVA has become detached from his structural support such that he is "free floating". The rotational mechanism could do little in supporting these conditions.

t. Item 18 - Because the manipulator is flexible under loading, if a capture latch should hang up, the combination of the low velocity and the deflection, would cause less rotation to be imparted to the passive vehicle than from a hard docking attempt using the rotational mechanism.

u. Item 19 - More separation can be maintained under any angle of docking approach when using the manipulators extended. This angle after manipulator attachment, can be adjusted for docking to give the least potential for impact between active and passive vehicles.

There would be no horizontal docking approach as the axis of the propellant tank module is 90° to the shuttle axis. In this case or possibly an intermediate position the distance between active and passive vehicles is reduced and the docking axis is fixed relative to the tank module axis. Because of the hazard related to impact between vehicles, the manipulator can under any angle maintain greater separation.

v. If an attempt is made to deploy the logistic element and proper release of the cargo bay attach fittings has not been effected, the manipulators will deflect or slip under the excess loading.

This would be noticed by the control operator and the operation could be stopped before damage occurs. Under the same condition for the rotational deployment mechanism, any rotational travel of the platform will cause damage of the logistic element, when the load is applied.

w. Item 21 - Because of the length and shape the manipulator can assume in any position, the problem of jettisoning the manipulator presents more risk of damage to the orbiter than the ejection of the structure of the rotational deployment mechanism, whose configuration remains unchanged.

6.3 SAFETY EVALUATION OF ORBITER ATTACHED VS ORBITER NOT ATTACHED FOR PROPELLANT TRANSFER

6.3.1 Introduction

In the propellant logistic transfer operation the orbiter may be attached during the transfer process, or it may be at a stand-off position. The objective was to evaluate the case of the orbiter attached vs not attached during propellant transfer from a safety viewpoint, independent of any specific configuration. This evaluation was needed for consideration of hazards for cases where the orbiter delivered propellants direct to the user.

6.3.2 Summary of Results

It was concluded from the results that the requirements for safety of combined configurations are greater when the orbiter is attached. Having integrated the man-rated requirements into attached systems the driving consideration is the time the orbiter crew will be committed to the transfer operation.

6.3.3 Safety Considerations and Evaluation of Orbiter Attached/Not Attached

The safety considerations used in the evaluation are contained in Table 6.3.3-1. The evaluation considers only those cases involved in propellant transfer operations.

6.3.4 Rationale for Case or Condition

a. Item 1 - The hazards to the orbiter crew, by their close proximity, is the greatest when attached. The transfer without the orbiter attached is remote from the control operator and in the event of any hazards, the mission may be lost with no effect on the crew.

b. Item 2 - Potential for loss of attitude control is least with the orbiter attached principally because of the reactive inertias. The large mass of the orbiter with a relatively light tug

SAFETY CONSIDERATIONS FOR EVALUATING ORBITER ATTACHED/NOT ATTACHED

Item	SAFETY CONSIDERATION	ORBITER ATTACHED	ORBITER NOT ATTACHED
1.	Potential hazard to control crew during transfer:		
	a. Fire	More	Less
	b. Explosion	More	Less
	c. Stabilization Disturbances	More	Less
2.	Potential for loss of attitude control:		
	a. Spinup	Less	More
	b. Spindown	Less	More
	c. During transfer	Less	More
	d. Linear acceleration	Less	More
3.	Potential of impact damage during docking propellant module to receiver:		
	a. Hard dock	Less	More
	b. Manipulator dock	More	Less
4.	Requirements for safety of combined configuration by:		
	a. Redundancy	More	Less
	b. Specification requirement for safety systems	More	Less
	c. Operational test	More	Less
	d. Factors of safety	More	Less
	e. Monitoring devices	More	Less
	f. Qualification tests	More	Less
	g. System checkout	More	Less
	h. Control capability	More	Less
	i. Warning devices	More	Less

Table 6.3.3-1

SAFETY CONSIDERATIONS FOR
EVALUATING
ORBITER ATTACHED/NOT ATTACHED

(Cont.)

Item	SAFETY CONSIDERATION	ORBITER ATTACHED	ORBITER NOT ATTACHED
4.	(Continued)		
	j. Venting systems location	More	Less
	k. Interlocks	More	Less
	l. Flowmeters capability	More	Less
	m. Disturbance Control	More	Less
	n. Emergency Shutdown	More	Less
	o. Emergency Separation	More	Less
5.	Time crew is committed to hazardous conditions	More	Less
6.	Potential hazards in effecting mating/demating of lines for transfer operation	Less	More
7.	Involvement of direction of acceleration and effect on safety of operation		
	a. Rotational	More	Less
	b. Linear	More	Less
8.	Potential to blackout communication by operating mode during transfer		
	a. Rotational	More	More
	b. Linear	Less	Less
9.	Potential hazards due to structural failure of configuration	More	Less

Figure 6.3.3-1 (Cont.)

attached can damp out disturbances during the four operative conditions listed. This coupled with the superior instrumentation of the orbiter control system provides less risk than having a remotely operated light mass reacting to disturbances and CG shift. The fluid surface distortion coupled with RCS action, when remotely controlled, could possibly produce severe oscillations in pitch or yaw.

c. Item 3a - Impact damage during hard dock with the orbiter attached appears to have less risk of damage than when not attached. This is predicated on the assumption that impact attenuation will be provided for both cases and that better control of the operation is provided by the orbiter crew in conjunction with its superior control capability. Docking aids will also be backed up with visual observations, whereas in the not attached case the operation is remote and control using TV aids may be more difficult in judging distances, conditions, etc., leading to a greater impact potential.

d. Item 3b - There is no major preference in this case. With the orbiter manipulators attached, one to the propellant module and one to the receiver, the two could be soft docked by slowly bringing the two elements together. Impact by loss of coordinated action could occur with minor disturbances. In the case where the manipulators do not control the receiver and module but just the module, stationkeeping alignment and docking can cause potential impact damage in the case of a missed docking with capture by one latch on the docking fixture, plus disturbances. The preference was thus given to the attached condition.

e. Item 4 - Because of the man-in-the-loop considerations with the orbiter attached, the entire configuration should be man-rated. The items a through o are essentially increased efforts in design, engineering, and test which must be taken in the interest of crew safety. Where the orbiter is not attached the factors will be somewhat reduced.

f. Item 5 - Since the crew will not be exposed directly with the orbiter not attached, the greater exposure is with the orbiter attached.

g. Item 6 - This relates to the number of operations involving mating and demating in the process. For the case of the orbiter attached, transfer line hookup can be made to involve only one mating and demating. In the operation of removing the propellant module out of the cargo bay and mating to the receiver there are two matings and two dematings required to return the configurations to the same condition in the cargo bay. Thus the orbiter attached case, having fewer operations and which eliminates disconnect in the cargo bay, has fewer hazards. These hazards

are leaking propellants, damaged insulation, lost pressurization through leaking QD seal, etc. **These hazards are involved in the case of the orbiter not attached, however, as stated before, they are not involved in the orbiter attached case.**

h. Item 7 - In both the cases a and b, with the orbiter attached failure of the deployment mechanism stabilization linkage could cause a rotational movement which would cause impact with the orbiter during spin up or spin down, or during the linear acceleration. The exception is the case where the tank module is not deployed out of the cargo bay. In this exception the hazards are fewer and comparable to the case where the orbiter is not attached.

i. Item 8 - In the rotational mode the rotating configuration can blank out the signal to ground control unless antenna location considers this condition. The antennas in a linear acceleration mode are capable of orientation without blackout. **Thus the linear acceleration mode was considered the safer mode.**

j. Item 9 - In the case where the orbiter is not attached, a catastrophic failure would cause loss of mission but the orbiter and crew would not be affected at their standoff position. With the orbiter attached, the same catastrophic failure could also damage the orbiter, with loss of mission. The loss of the orbiter and crew is a potential possibility.

6.4 SAFETY COMPARISON OF FOUR TUG PROPELLANT TRANSFER CONCEPTS

6.4.1 Introduction

Four concepts were evaluated from a safety viewpoint involving the tug element in a fluid transfer operation. **The orbiter was considered attached in three concepts and not attached in the fourth. The objective of this study was to identify the concept preferred from a system safety standpoint. These tug transfer concepts involved the orbiter attached for both** rotational and linear acceleration and detached tank module with linear acceleration for propellant settling.

6.4.2 Summary of Results

Of the four configurations evaluated, Concept A, using rotational transfer with logistic tank in the cargo bay, when provided with an Apollo type probe at the docking interface, is preferred from the system safety viewpoint over the other approaches. The difference between Concept A and Concept D does not appear to present a major safety problem. See Table 6.4.2-1.

EVALUATION FOR TUG PROPELLANT LOGISTIC ELEMENT

	CONFIGURATION			
SAFETY CONSIDERATION	A	B	C	D
1. NUMBER OF CRITICAL OPERATIONS	1	2	2	2
2. NUMBER OF FAILURE EFFECTS:				
A. ON CREW	3	3	3	1
B. ON STRUCTURE	1 (A)	2	2	3 (B)
3. CREW EXPOSURE TO RISKS DURING NORMAL OPERATIONS	3 (C)	3 (C)	3 (C)	1 (D)
4. ATTITUDE CONTROL CAPABILITY OF TOTAL CONFIGURATION	1	2	2	2
5. IMPACT CONTROL	1	3 (E)	3 (E)	3 (F)
6. **MAN-COMPATIBILITY**				
A. TUG	1	1	1	2 (G)
B. PROPELLANT TANK MODULE	1	1	1	2 (G)
7. COMMUNICATION CONTROL	2	2	1	1
8. LEAKAGE CONTROL	1	2 (H)	2 (H)	2 (I)
TOTAL	15	21	20	19
OVERALL RATING	1	2	2	2

1 = BEST
4 = WORST

(A) GREATER STABILITY OF CONF
(B) LOSS OF REMOTE CONTROL CAP
(C) LONGER TRANSFER TIME
(D) ORBITER AT STANDOFF DURING TRANSFER
(E) HARD DOCK INVOLVED
(F) ADD RENDEZVOUS & DOCKING
(G) SOME SUBSYSTEM NOT MAN-RATED
(H) FLEX HOSE IN SYSTEM
(I) ADDITIONAL DISCONNECTS

TABLE 6.4.2-1

6.4.3 Candidate Concepts

The four candidate configurations evaluated from a safety viewpoint are schematically portrayed in Figures 6.4.3-1 through 6.4.3-4. Concept A was rotational transfer with logistic tank in the cargo bay; Concept B was rotational transfer with orbiter attached and propellant tank module deployed; Concept C was linear transfer with orbiter attached and propellant tank module deployed; and Concept D was linear acceleration of tug with tank module-orbiter not attached.

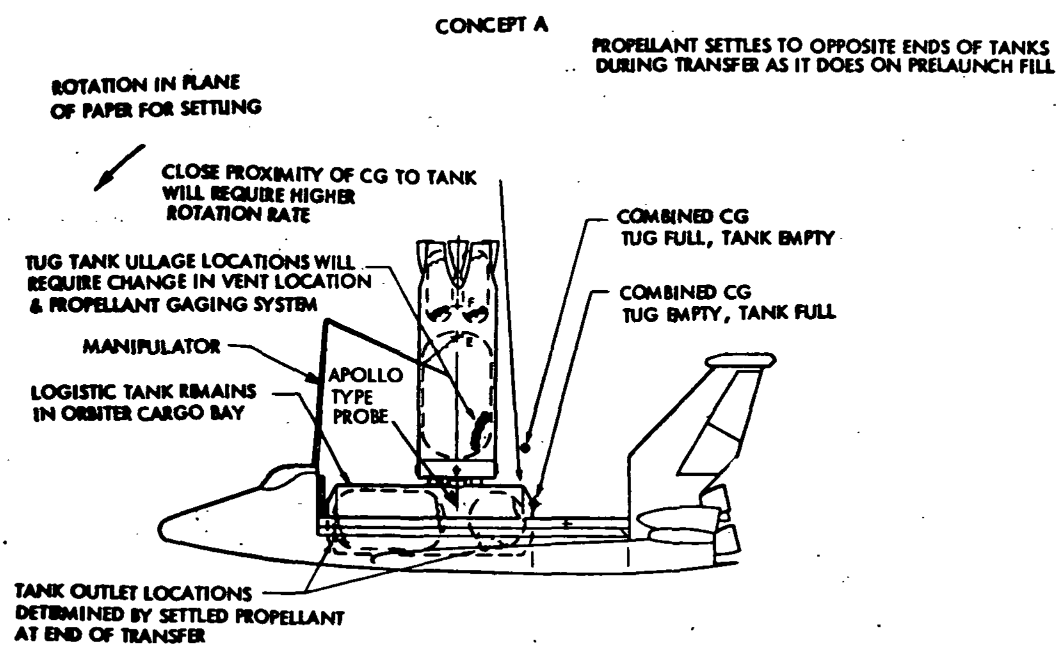


Figure 6.4.3-1 Rotational Transfer with Logistic Tank in Cargo Bay

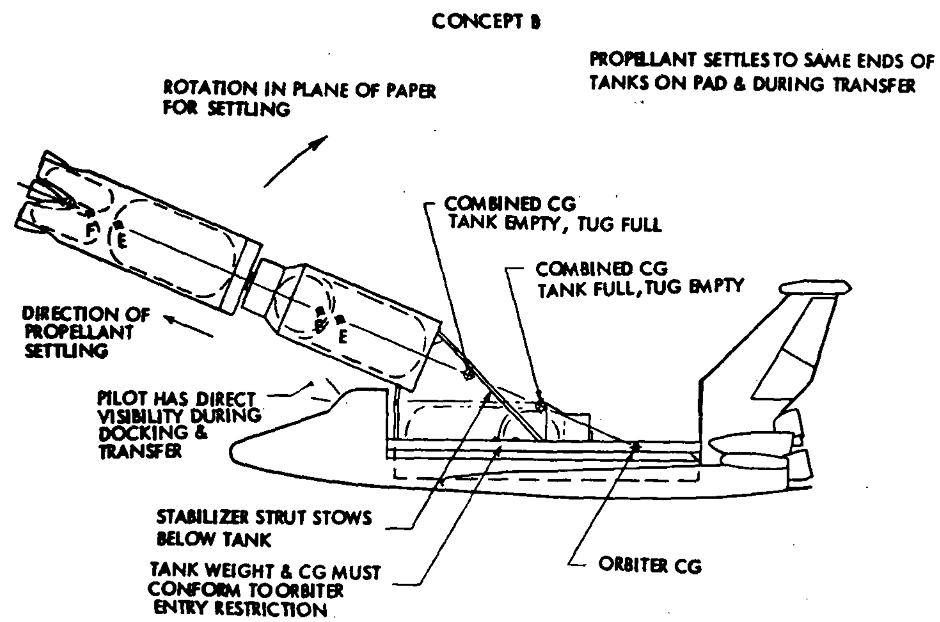


Figure 6.4.3-2 Rotational Transfer with Orbiter Attached

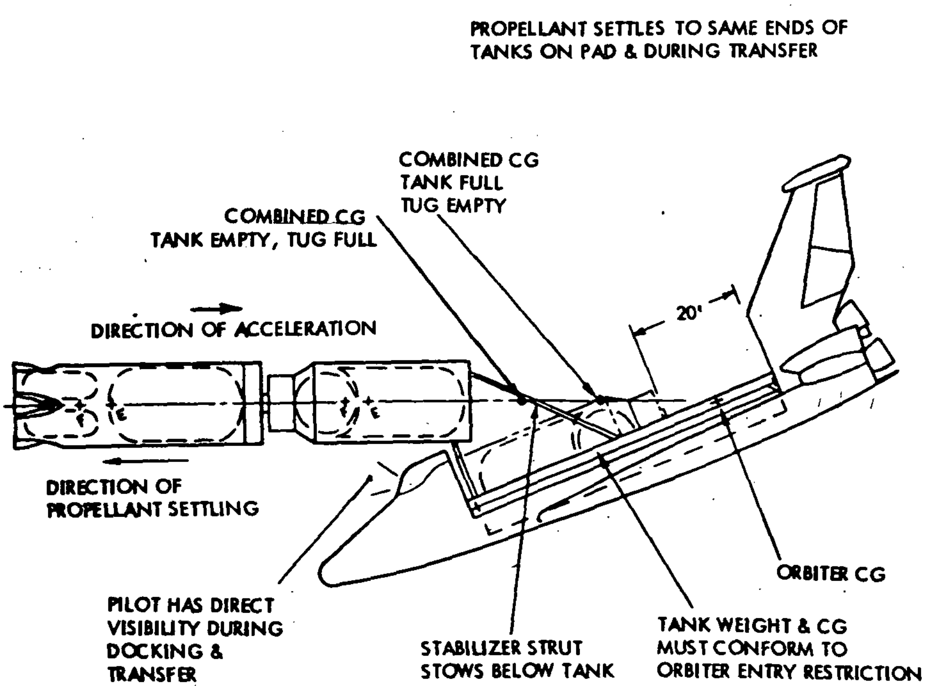


Figure 6.4.3-3 Concept C Linear Transfer with Orbiter Attached

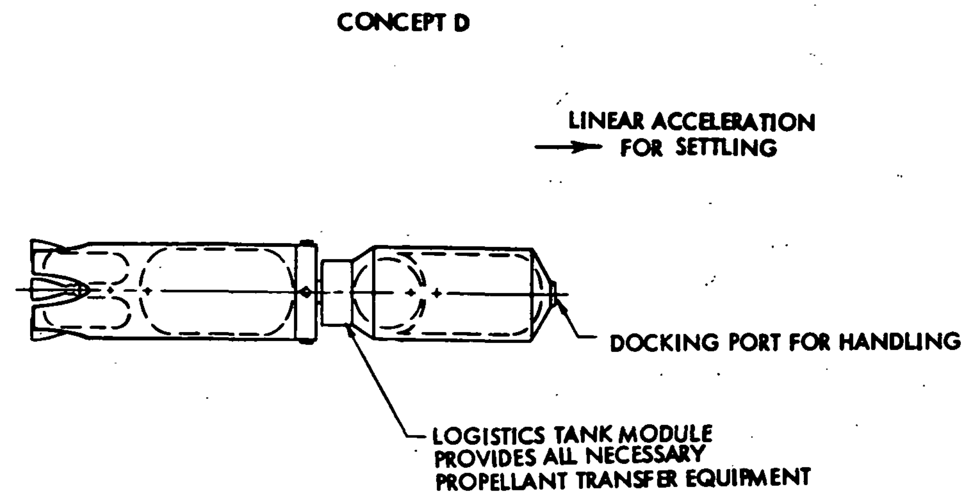


Figure 6.4.3-4 Direct Linear Transfer to Tug (Orbiter Detached)

6.4.4 Safety Considerations for Evaluating Propellant Logistic Elements

a. Number of Critical Operations

This evaluates the critical operations covering the orbital operations from the time the orbiter arrives with the propellant tank module through deployment, docking, transfer and retrieval.

b. Number of Failure Affects

1. On the Crew

This item evaluates the major potential hazards to the crew as a result of the affects of a failure during deployment, docking, transfer and retrieval.

2. On the Structure

This item evaluates the major potential hazards to the structure as a result of the affects of a failure during a critical operation.

c. Crew Exposure to Risks During Normal Operations

This evaluation item covers the risks associated with a time line during which the propellant logistic elements are engaged in fluid transfer.

d. Attitude Control Capability of Total Configuration

This evaluation item covers those aspects of the configuration dealing with control of disturbances, structural interaction and RCS operation.

e. Impact Control

This evaluation item covers those operations during deployment, docking, transfer and retrieval which are directly relatable to potential impact conditions.

f. **Man-Compatibility**

1. Tug

This evaluation item covers the requirements, or lack thereof, of man-rating of the tug as it relates to its functioning in relation to the orbiter.

2. Propellant Tank Module

This evaluation item covers the requirements, or lack thereof, of man-rating of the tank module as it relates to its functioning in relation to the orbiter.

g. Communication Control

This item evaluates the continuity of maintaining communications in the operational mode during transfer.

h. Leakage Control

This evaluation item covers the major factors contributing to leakage, by configuration.

Data supporting these considerations are contained in Tables 6.4.4-1 through 6.4.4-10.

Safety Considerations for Evaluating
Propellant Logistics Elements
Number of Critical Operations

Operation	Concept A	Concept B	Concept C	Concept D
Rendezvous	Same	Same	Same	Same
Maneuver	Same	Same	Same	Same
Deploy Module	1. Never deployed - provides safest condition.	1. Impact hazards where manipulators are used alone to deploy module out of cargo bay.	1. Impact hazards where manipulators are used alone to deploy module out of cargo bay.	1. Impact hazards where manipulators are used alone to deploy module out of cargo bay.
	2. Connections never broken.	2. Requires disconnect of line interconnect fixture in cargo bay providing potential leakage or heavy flex lines are required.	2. Requires disconnect of line interconnect fixture in cargo bay providing potential leakage or heavy flex lines are required.	2. Requires disconnect of line interconnect fixture in cargo bay providing potential leakage or heavy flex lines are required.
	3. No mechanism required - no deployment.	3. Potential for mechanism failure during deployment.	3. Potential for mechanism failure during deployment.	3. Potential for mechanism failure during deployment.
Station Keep	Same	Same	Same	Same

Table 6.4.4-1

Safety Considerations for Evaluating
Propellant Logistics Elements
Number of Critical Operations

Operation	Concept A	Concept B	Concept C	Concept D
Dock & Rigidize	1. Provides stability during docking to dampen disturbances. 2. Provides least impact potential. 3. Restrained so impact could not occur, through use of stabilization probe (Apollo type).	1. Potential Impact from disturbances. 2. Impact from loss of deployment aids, over control and off center docking approach. 3. Impact from passive vehicle rotation during hard dock due to missed alignment.	1. Potential impact from disturbances. 2. Impact from loss of deployment aids, over control and off center docking approach. 3. Impact from passive vehicle rotation during hard dock due to missed alignment.	1. Potential impact from disturbances. 2. Impact from loss of deployment aids, over control and off center docking approach. 3. Impact from passive vehicle rotation during hard dock due to missed alignment.
Line Interconnect Fixtures Rigidized	Same	Same	Same	Same
Line Connections Made	Same	Same	Same	Same
Propellant Settling	1. Rigidized manipulators provide additional stability.	1. Potential impact if stabilization strut or fitting fail.	1. Potential impact if stabilization strut or fitting fail.	1. Operation by remote operation. Fair stability expected.

Table 6.4.4-1 (Cont.)

Safety Considerations for Evaluating
Propellant Logistics Elements
Number of Critical Operations

Operation	Concept A	Concept B	Concept C	Concept D
Pressurization	1. Could be supplied by orbiter system under better control. If not, this then is the same as the others.	1. Potential loss of control of gas generator or heat exchanger causing fire/explosion.	1. Potential loss of control of gas generator or heat exchanger causing fire/explosion.	1. Potential loss of control of gas generator or heat exchanger causing fire/explosion.
Childown	1. Process for fluid transfer generally similar.	1. Process for fluid transfer generally similar.	1. Process for fluid transfer generally similar.	1. Process for fluid transfer generally similar.
Transfer	1. Disturbance factor reduced due to stabilizing support by manipulators and aligning device.	1. Disturbances accentuated by configuration.	1. Disturbances accentuated by configuration.	1. Disturbances from fluid inlet momentum, CG shift, sloshing may be minor could be major.
	2. Inertia of configuration assists in wobble reduction.	2. Configuration wobble potential with structural deflection and sloshing.	2. Configuration wobble potential with structural deflection and sloshing.	2. Not applicable.
	3. Not applicable.	3. Impact in case where stabilizer strut joints fail during rotation.	3. Impact in case where stabilizer strut joints fail during rotation.	3. Not applicable.

Table 6.4.4-1 (Cont.)

Safety Considerations for Evaluating
Propellant Logistics Elements
Number of Critical Operations

Operation	Concept A	Concept B	Concept C	Concept D
Transfer	4. Mass spill due to line rupture could contaminate area of orbiter with ice crystals.	4. Mass spill due to line rupture could contaminate area of orbiter with ice crystals.	4. Mass spill due to line rupture could contaminate area of orbiter with ice crystals.	4. Not applicable.
	5. Stabilization of system reduces the potential for loss of quantity transferred data.	5. Loss of quantity of transferred fluid causing overfill/underfill.	5. Loss of quantity of transferred fluid causing overfill/underfill.	5. Loss of quantity of transferred fluid causing overfill/underfill.
Line Draining	Same	Same	Same	Same
Depressurization	1. Failure of the vent valve to reseat causing eventual loss of pressure.	1. Failure of the vent valve to reseat causing eventual loss of fluids and pressure.	1. Failure of the vent valve to reseat causing eventual loss of pressure.	1. Failure of the vent valve to reseat causing eventual loss of pressure.
	2. Contamination of local orbiter area by ice.	2. Contamination of local orbiter area by ice.	2. Contamination of local orbiter area by ice.	2. Not applicable.
Terminate Acceleration or despin	1. Not applicable.	1. Potential impact if stabilization strut or fittings fail.	1. Potential impact if stabilization strut or fittings fail.	1. Not applicable.

Table 6.4.4-1 (Cont.)

Safety Considerations for Evaluating
Propellant Logistics Elements
Number of Critical Operations

Operation	Concept A	Concept B	Concept C	Concept D
Terminate Acceleration or despin	2. Potential for instability of configuration is reduced from other configurations.	2. Instability due to RCS/dynamics/sloshing interaction	2. Instability due to RCS/dynamics/sloshing interaction.	2. Potential for instability due to RCS/dynamics/sloshing interaction.
	3. Failure requiring emergency termination of operation may accentuate the hazard.	3. Failure requiring emergency termination of operation may accentuate the hazard.	3. Failure requiring emergency termination of operation may accentuate the hazard	3. Failure requiring emergency termination of operation may accentuate the hazard.
	4. Loss of RCS capability reduced by redundancy.	4. Loss of RCS capability reduced by redundancy.	4. Loss of RCS capability reduced by redundancy.	4. Failure of RCS because of less redundancy in system a potential hazard.
Checkout	1. Good data monitoring capability with controls available.	1. Good data monitoring capability with controls available.	1. Good data monitoring capability with controls available.	1. Loss of communication is a potential hazard due to remote operation.
Undock	1. Same	1. Same	1. Same	1. Same
	2. Visual monitoring good.	2. Visual monitoring good.	2. Visual monitoring good.	2. Maneuvers by orbiter for visual checkout could lead to impact hazard.

Table 6.4.4-1 (Cont.)

Safety Considerations for Evaluating
Propellant Logistics Elements
Number of Critical Operations

Operation	Concept A	Concept B	Concept C	Concept D
Retrieval	1. No retrieval necessary - never deployed.	1. Requires rotation into the cargo bay. 2. Flexlines for venting and offload of residual propellants through the orbiter system could fail due to entanglement.	1. Requires rotation into the cargo bay. 2. Flexlines for venting and offload of residual propellants through the orbiter system could fail due to entanglement.	1. Impact potential during retrieval of tank module. 2. Soft dock made. 3. Line interconnect fixture must be reconnected to rotational deployment mechanism of shuttle interface.
Secure	1. Securing needed to stow manipulators.	1. Module stowing and locking to attach points in cargo bay required. 2. Rotational mechanism requires latching for safety during deorbit.	1. Module stowing and locking to attach points in cargo bay required. 2. Rotational mechanism requires latching for safety during deorbit.	1. Module stowing and locking to attach points in cargo bay required. 2. Manipulator need stowing.

Table 6.4.4-1

NUMBER OF FAILURE EFFECTS ON CREW

CONCEPT A	CONCEPT B	CONCEPT C	CONCEPT D
1. Crew exposed to the effects of a failure throughout the entire deployment, transfer, docking and retrieval process:	1. Crew exposed to the effects of a failure throughout the entire preparation, transfer and securing process:	1. This is the same as Concept B, except this involves linear acceleration and termination instead of spin up/spin down. Items d., g., and i. are not applicable.	1. Crew only exposed to the effects of a failure during deployment, docking and retrieval operations.
a. Failure of a manipulator which will not allow the cargo bay doors to close for re-entry.	a. Failure of the rotational deployment mechanism in any intermediate position or to properly retract would not allow the cargo bay doors to close for re-entry.		a. Same as Concept A and B as a combination.
b. Impact of the manipulators with the tug during tug capture for docking, which causes uncontrolled venting, ice crystals in orbiter area, and adverse vehicle control problems.	b. Failure of the rotational deployment mechanism due to faulty alignment at docking causing impact damage affecting re-entry conditions of orbiter.		b. Same as Concept A.

TABLE 6.4.4-2

NUMBER OF FAILURE EFFECTS ON CREW

CONCEPT A	CONCEPT B	CONCEPT C	CONCEPT D
c. Failure of manipulators to overcontrol or by going out of control involves potential impact with tank module.	c. Failure of the stabilization strut during spin up or spin down could cause damage to the orbiter by having the configuration swing into the orbiter structure. When this occurs at the forward end of the orbiter it could cause pressure hull damage in the crew area.		c. Same as Concept A.
d. Failure of the RCS to shut off after spin up of configuration causing excessive RPM.	d. Same as Concept A.		d. Line interconnect fixtures demating from the rotational mechanism may cause ice crystal formation in the cargo bay.

TABLE 6.4.4-2

NUMBER OF FAILURE EFFECTS ON CREW

CONCEPT A	CONCEPT B	CONCEPT C	CONCEPT D
e. Any leakage into the orbiter cargo bay which is not detected and eliminated before re-entry could cause fire/explosion.	e. Leakage which causes ice crystal formation in the transfer area reduces crew capability during operation.		e. Transfer failures would not affect the crew because the orbiter will be on stand-by during the transfer period.
f. Any catastrophic failure during fluid transfer producing an explosion may: (1) Damage the orbiter by fragmentation impact in the ECLSS radiator panels. (2) Open or cause fragments to penetrate the pressure hull. (3) Penetrate the propellant tank module causing	f. Any catastrophic failure during fluid transfer producing an explosion may: (1) Damage the orbiter by fragmentation impact in the ECLSS radiator panels. (2) Open or cause fragments to penetrate the pressure hull.		f. Failure causing hangup of tug at undocking gives potential for impact and loss of vehicle control.

TABLE 6.4.4-2

NUMBER OF FAILURE EFFECTS ON CREW

CONCEPT A	CONCEPT B	CONCEPT C	CONCEPT D
explosive potential on earth return.			
g. Failure of the capability to despin causing the crew and orbiter to continue in a spin condition.	g. Failure of the capability to despin causing the crew and orbiter to continue in a spin condition.		g. Failure to mate with the line interconnect fixture interface of the rotational mechanism, which causes leakage or venting presents hazards during re-entry.
h. Failure causing hangup at undocking gives potential for impact and loss of vehicle control.	h. Same as Concept A.		h. Risk of impact during stowing of empty tank in cargo bay if mechanism is failed and not noted.
i. Failure to maintain CG alignment causing shift of gravity force on the crew.	i. Same as Concept A.		
	j. Risk of impact during stowing of emptytanks in cargo bay if mechanism is failed and not noted.		

TABLE 6.4.4-2

NUMBER OF FAILURE EFFECTS ON STRUCTURE

CONCEPT A	CONCEPT B	CONCEPT C	CONCEPT D
1. The tank structure is double walled, heavier and in the docking ring area is capable of larger loads from impact than other configurations because of its attachment to the orbiter structure.	1. Hard docking could create potential stabilization strut failure.	Same as Concept B except for item 4 where linear acceleration and deceleration is used.	1. Hard docking tug to module could damage deployment mechanism.
2. Because the tank is not deployed and the manipulator arms brace the tug, there is greater stability in the configuration.	2. Disturbances create stressing of structure of deployment mechanism.		2. Combined use of manipulators and deployment mechanism allows soft dock.
3. Least potential for fire	3a. During reconnect there is a potential for propellant leakage into cargo bay with possible overpressure damage during reentry. 3b. Where large flex lines are used they could get kinked and damaged being folded into the cargo bay,		3. Configuration subject to disturbances of sloshing and RCS action.

Table 6.4.4-3

NUMBER OF FAILURE EFFECTS ON STRUCTURE

CONCEPT A	CONCEPT B	CONCEPT C	CONCEPT D
	3b. (Cont.) stressed due to their size, length and suspension. This could cause over-stress in the localized area of the tug and orbiter interfaces.		
4. Soft docking of the tug reduces structural energy absorption requirement.	4. Loss of stabilizing linkage could cause structural damage during spin up and spin down.		4. Failure in manipulators or deployment mechanism requires emergency separation of system.
5. Missed docking not a factor here as docking is controlled by manipulators and long probe hookup for stabilization.	5. Damage could occur while rotating the propellant module into the cargo bay.		5. Impact damage through loss of remote control override capability to stabilize the configuration for redocking of the propellant module.
	6. Hangup of capture latch on missed docking could cause structural damage.		6. Hangup of capture latches can cause structural damage.

Table 6.4.4-3 (Cont.)

NUMBER OF FAILURE EFFECTS ON STRUCTURE

CONCEPT A	CONCEPT B	CONCEPT C	CONCEPT D
			7. Failure of the line interconnect fixture rigidizing probes to release after derigidizing can cause damage to fixture. 8. Failure of the GG or heat exchanger due to loss of remote monitoring and control could burn through structure.

Table 6.4.4-3 (Cont.)

CREW EXPOSURE RISKS DURING NORMAL OPERATIONS

CONCEPT A	CONCEPT B	CONCEPT C	CONCEPT D
Crew exposed for the entire period during which propellants are transferred. The rotational mode for propellant transfer could be from eight to fifteen hours depending on transfer rates.	Same as Concept A.	Same as Concept A.	In this concept, the crew is not in the area of the tug/tank module during transfer and thus reduces the crew exposure during transfer to that of those which are a function of the orbiter alone.

TABLE 6.4.4-4

ATTITUDE CONTROL CAPABILITY OF TOTAL CONFIGURATION

CONCEPT A	CONCEPT B	CONCEPT C	CONCEPT D
1. Because of the mass of the orbiter and bracing of the tug by the manipulators and securing probe, the dynamic stability of this configuration will reduce disturbance factors for control.	1. This configuration would be subjected to disturbances which are not as easy to damp out, as in Concept A, due to the deployment mechanism structural frame interaction between the tug/propellant module and the orbiter.	1. Same as Concept B.	1. Because of the light mass of the tug/propellant tank module, the reaction to fluid surface distortion and disturbances, automatically reacted upon by the RCS of the tug or controlled by crew remote operational override, could produce instability in the configuration.
2. Operation of the orbiter RCS for spin up is minimal, as is it for spin down. These engines produce greater thrust and possess redundancy for man-rating.	2. Same as Concept A.	2. The long duration of time for RCS burn for propellant settling (8 to 15 hrs) could reduce thrusts for vehicle control by throat errosion of the nozzle.	2. Same as Concept C.
	3. Failure of the undocking attempt to make a clean separation, where the vehicles are still captured but not rigidized could lead to loss of vehicle control or structural damage.	3. Same as Concept B.	

TABLE 6.4.4-5

IMPACT CONTROL

CONCEPT A	CONCEPT B	CONCEPT C	CONCEPT D
This configuration is assessed to have fewer impact aspects than the others due to:		Same as Concept B except item 4 is applicable to linear acceleration or acceleration termination.	
1. The manipulators can bring the tug to within three feet of the cargo bay tank and stop.	1. Failure of the rotational mechanism support struts could cause impact during deployment.		1. Requires an additional rendezvous which, with depletion of tug propellants or misoperation, could cause impact.
2. Disturbances to the tug at that time could not be great enough to spring the manipulators enough to cause impact.	2. Hard docking increases damage potential because of energy absorption being transmitted to deployment mechanism.		2. Impact at tug due to disturbance of propellant module on end of manipulators.
3. A probe mechanism can be used at the docking interface to capture the docking end and provide three point stabilization to the tug.	3. Missed docking attempt can cause unstabilizing force to tug, with possible rotational component which could cause impact.		3. Additional undock and dock operation gives additional potential for impact.

Table 6.4.4-6

IMPACT CONTROL

CONCEPT A	CONCEPT B	CONCEPT C	CONCEPT D
4. The stabilizing probe can bring the tug to dock in coordination with manipulator movement. 5. The tank is of two shelled construction and the outer shell can be structurally stronger. The docking interface can be tied into the orbiter structure. 6. There are no tank deployment failures in this concept, reducing impact potential.	4. Failure of the stabilizing strut could cause impact of the pressure hull during spin up or orbiter tail during spin down. 5. Failure or damage to the rotational mechanism struts from hard docking could cause impact, due to misalignment, between the tank module and cargo bay.		4. Potential for impact with cargo bay walls where deployed with manipulators.

Table 6.4.4-6 (Cont.)

CONCEPT A	CONCEPT B	CONCEPT C	CONCEPT D
1. In all modes the tug and orbiter will function together as a configuration and are required to be man rated when attached for propellant transfer.	1. Same as Concept A.	1. Same as Concept A.	1. Because the tug is in a passive mode, the soft docking process by manipulators or hard dock to the propellant tank module does not require all systems to be man rated. With the translation away from tug/propellant tank module, the system is not attached to the orbiter and will thus not affect the crew upon system activation. Loss of capability due to a hazard would involve mission degradation. 2. The orbiter will always be man rated. 3. From a safety point of view, item 1 reduces the safety of the mission capability.

TABLE 6.4.4-7

MAN-COMPATIBILITY - PROPELLANT TANK MODULE

CONCEPT A	CONCEPT B	CONCEPT C	CONCEPT D
With the propellant tank module a part of the configuration during propellant transfer, the tank module must be man rated	Same as A.	Same as A.	Because the propellant tank module is not activated until after the orbiter has translated away to a stand off position, the tank does not have to have all systems man rated. However, all factors of safety for using the module in the cargo bay of the orbiter must be met. From a safety point of view this reduced requirement reduces the safety of the mission capability.

Table 6.4.4.-8

COMMUNICATIONS CONTROL

CONCEPT A	CONCEPT B	CONCEPT C	CONCEPT D
Rotation of orbiter may result in an orientation which blacks out communication, due to blanking of the antenna	Same as A	Orientation of antenna can be maintained with ground stations, or satellite relay.	Same as C During transfer, communication with the orbiter must be maintained. Loss of this contact could reduce crew command override capability.

Table 6.4.4-9

LEAKAGE CONTROL

CONCEPT A	CONCEPT B	CONCEPT C	CONCEPT D
1. No propellant module fluid line disconnects to orbiter need be made. 2. One propellant line interconnect fixture mating and demating required to tug. 3. Increased stability causes less working of QD's. 4. Line extension bellows potential failure point causing leakage.	1. Where no flex lines are used, the line interconnect fixture must be demated from the orbiter connection. 2. Line interconnect fixture must be mated with potential for leakage. 3. If flex lines are used to eliminate the requirements of 1 above, the potential for leakage due to line break from entanglement or pinching during stowing exists. 4. Disturbance may cause structural deflection causing leakage at tug/tank interface. 5. Line extension bellows potential failure point causing leakage	Same as B	1. Fluid lines are demated from orbiter, mated to tug, demated from tug, and remated to orbiter. More operations of the line extension bellows also exist which together increase potential for leakage. 2. Disturbances causing flexure of the configuration during transfer could possibly cause leakage past QD seals. 3. During placement of the propellant tank module in the cargo bay, impact of the tank with projection in the bay could cause tank leakage.

Table 6.4.4-10

6.5 SAFETY COMPARISON OF FOUR CIS/RNS TRANSFER CONCEPTS

6.5.1 Introduction

Four concepts were evaluated from a safety viewpoint involving the CIS/RNS element in a fluid transfer operation with the orbiter attached, and three with the orbiter not attached. All involved hard docking of the propellant tank module. The objective of this study was to identify the concept preferred from a system safety standpoint. The CIS/RNS concepts included rotational and linear acceleration for propellant settling and propellant control by capillary methods for propellant orientation.

6.5.2 Summary of Results

Of the four candidate configurations evaluated, the mode of CIS/RNS propellant transfer preferred from a system safety standpoint was Concept C which was the CIS/RNS and propellant tank module docked and linearily accelerated for propellant settling. Concepts C and D were rated overall the same, however, Concept C was preferred because of the potential risks **in a capillary system in attainment of a safe system, considering the state-of-the-art. See Table 6.5.2 for overall evaluation rating.**

6.5.3 Candidate Concepts

The four candidate configurations evaluated from a system safety viewpoint are schematically portrayed in Figure 6.5.3-1.

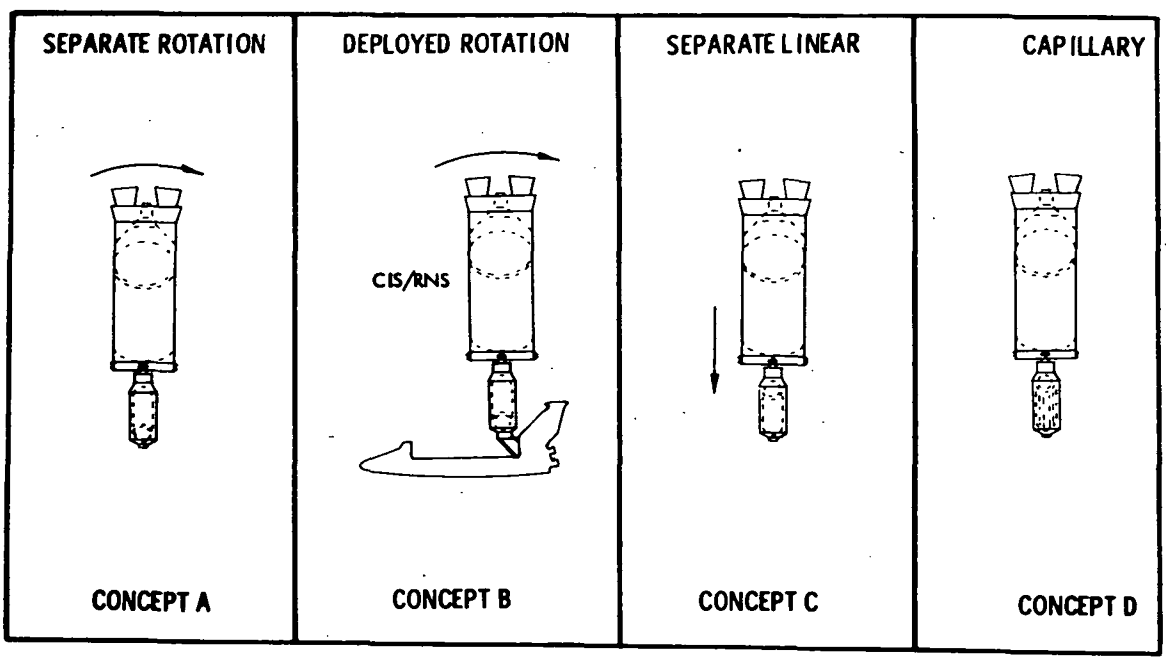


Figure 6.6.3-1 Transfer Options for Typical CIS/RNS Concepts

EVALUATION FOR CIS/RNS PROPELLANT
LOGISTIC ELEMENTS

SAFETY CONSIDERATION	CONFIGURATION		
	ROTATION CONCEPT B	LINEAR CONCEPT C	CAPILLARY CONCEPT D
NUMBER OF CRITICAL OPERATIONS	3	1	1
NUMBER OF FAILURE EFFECTS:			
A. ON CREW	3	1	1
B. ON STRUCTURE	3	1	2
CREW EXPOSURE TO RISKS DURING NORMAL OPERATIONS	2	1	1
ATTITUDE CONTROL CAPABILITY OF TOTAL CONFIGURATION	3	2	1
IMPACT CONTROL	2	1	1
MAN-COMPATIBILITY			
CIS/RNS	1	1	1
PROPELLANT TANK MODULE	1	2	2
COMMUNICATION CONTROL	2	1	1
LEAKAGE CONTROL	2	1	1
TOTAL	22	12	12
OVERALL RATING	3	1	1

TABLE 6.5.2-1

Concept A was rotational transfer with orbiter not attached.
Concept B was rotational transfer with orbiter attached.
Concept C was linear acceleration with orbiter not attached.
Concept D was capillary transfer.

Concepts A and B using rotational acceleration for propellant settling have conditions of ullage control which result from the CG of the configuration falling within the CIS/RNS tankage. It was therefore decided to evaluate Concept B only **since hazards of Concept A are included in Concept B. The hazards involving the orbiter attached in Concept B thus gave a better comparison for evaluation.**

6.5.4 Safety Considerations for Evaluating Propellant Logistic Elements

a. Number of Critical Operations

This evaluates the critical operations covering the orbital operations from the time the orbiter arrives with the propellant tank module through deployment, docking, transfer and retrieval.

b. Number of Failure Affects

1. On the Crew

This item evaluates the major potential hazards to the crew as a result of the affects of a failure during deployment, docking, transfer, and retrieval.

2. On the Structure

This item evaluates the major potential hazards to the structure as a result of the affects of a failure during a critical operation.

c. Crew Exposure to Risks During Normal Operations

This evaluation item covers the risks associated with a time line during which the propellant logistic elements are engaged in fluid transfer.

d. Attitude Control Capability of Total Configuration

This evaluation item covers those aspects of the configuration dealing with control of disturbances, structural interaction and RCS operation.

e. Impact Control

This evaluation item covers those operations during deployment, docking, transfer, and retrieval which are directly relatable to potential impact conditions.

f. **Man-Compatibility**

1. CIS/RNS

This evaluation item covers the requirements or lack thereof of man-rating of the CIS/RNS as it relates to its functioning in relation to the orbiter.

2. Propellant Tank Module

This evaluation item covers the requirements or lack thereof of man-rating of the tank module as it relates to its functioning in relation to the orbiter.

g. Communication Control

This item evaluates the continuity of maintaining communications in the operational mode during transfer.

h. Leakage Control

This evaluation item covers the major factors contributing to leakage, by configuration.

Data supporting these considerations are contained in Tables 6.5.4-1 through 6.5.4-10.

**Safety Considerations for Evaluating
Propellant Logistics Elements
Number of Critical Operations**

OPERATION	CONCEPT B	CONCEPT C	CONCEPT D
RENDEZVOUS	RENDEZVOUS IS ALL THE SAME FOR CONFIGURATIONS B, C, & D		
MANEUVER	MANEUVER OPERATIONS ARE THE SAME FOR CONFIGURATIONS B, C, & D - MUST BE INSIDE CONE OF RADIATION SHIELD FOR RNS		
DEPLOY MODULE	DEPLOYMENT BY ROTATIONAL DEPLOYMENT DEVICE IS THE SAME FOR CONFIGURATIONS B, C, & D		
STATIONKEEP	STATIONKEEPING IS THE SAME FOR CONFIGURATIONS B, C, & D - MUST BE INSIDE CONE OF RADIATION SHIELD FOR RNS		
DOCK & RIGIDIZE	THESE OPERATIONS ARE THE SAME FOR CONFIGURATIONS B, C, & D		
UNDOCK ORBITER FROM MODULE	NOT APPLICABLE	UNDOCK FROM PROPELLANT MODULE. POTENTIAL IMPACT IF NOT STABILIZED	UNDOCK FROM PROPELLANT MODULE. POTENTIAL IMPACT
LINE INTERCONNECT FIXTURES RIGIDIZED	FAILURE TO RIGIDIZE CAUSES LEAKAGE AT Q.D. ON ACTIVATION	FAILURE TO RIGIDIZE CAUSES LEAKAGE AT Q.D. ON ACTIVATION	FAILURE TO RIGIDIZE CAUSES LEAKAGE AT Q.D. ON ACTIVATION
LINE CONNECTIONS MADE	FAILURE TO MAKE CONNECTIONS PROPERLY CAUSES DELAY OF MISSION OR DAMAGE	FAILURE TO MAKE CONNECTIONS PROPERLY CAUSES DELAY OF MISSION OR DAMAGE	FAILURE TO MAKE CONNECTIONS PROPERLY CAUSES DELAY OF MISSION OR DAMAGE
PROPELLANT SETTLING	ORBITER USED FOR ROTATIONAL ACCELERATION OF CONFIGURATION 1. DISTURBANCE FACTOR POTENTIAL 2. FLUID/VAPOR INTERFACE CONTROL PROBLEMS DUE TO CG FALLING INTO CIS/RNS TANK	LINEAR ACCELRATION BY RCS 1. POTENTIAL DISTURBANCE FACTORS	CAPILLARY METHODS MAINTAIN FLUIDS WITHOUT ACCELERATION FORCES

Table 6.5.4-1

OPERATION	CONCEPT B	CONCEPT C	CONCEPT D
	3. SHORT RCS OPERATING TIME TO ACHIEVE ACCELERATION 4. POTENTIAL COMMUNICATIONS BLOCKOUT		
PRESSURIZATION	PRESSURIZED BY G.G. & H.E. IN PROPELLANT TANK MODULE 1. POTENTIAL FIRE/EXPLOSION IF REGULATION TO G.G. & H.E. IS LOST	PRESSURIZED BY G.G. & H.E. IN PROPELLANT TANK MODULE 1. POTENTIAL FIRE/EXPLOSION IF REGULATION TO G.G. & H.E. IS LOST	MAINTAINED BY THERMODYNAMIC VENT CONTROL SYSTEM 1. EXCESSIVE VENTING IF THEROMODYNAMIC VENT CONTROL FAILS
CHILLDOWN	SLOW FILL REQUIRED FROM PUMP TO PREVENT STRUCTURAL FAILURES OF LINES, ETC.	SLOW FILL REQUIRED FROM PUMP TO PREVENT STRUCTURAL FAILURES OF LINES, ETC.	SLOW FILL REQUIRED FROM PUMP TO PREVENT STRUCTURAL FAILURES OF LINES, ETC.
TRANSFER	BECAUSE OF THE CONFIGURATION, DISTURBANCES IN FLUID SURFACE DISTORTION, LIQUID/VAPOR INTERFACE CONTROL, & POTENTIAL DYNAMIC COUPLING COULD BE EXPECTED SPILL COULD CONTAMINATE THE AREA WITH ICE CRYSTALS	LITTLE DYNAMIC COUPLING OR DISTURBANCE EFFECTS ON THIS CONFIGURATION EXCEPT FROM FLUID SURFACE DISTORTION RCS MUST OPERATE OVER ENTIRE PERIOD OF TRANSFER ORBITER AT STANDOFF DURING TRANSFER OPERATIONS	FEW DISTURBANCE FACTORS DURING TRANSFER INITIAL FILLING OF TANK MAY WET SCREWS WHICH TRAP VAPOR GIVING ERRONEOUS READING OF LOAD

Table 6.5.4-1 (Continued)

OPERATION	CONCEPT B	CONCEPT C	CONCEPT D
LINE DRAINING	BECAUSE OF THE CONFIGURATION, DISTURBANCES IN FLUID SURFACE DISTORTION, LIQUID/VAPOR INTERFACE CONTROL, & POTENTIAL DYNAMIC COUPLING COULD BE EXPECTED SPILL COULD CONTAMINATE THE AREA WITH ICE CRYSTALS	LITTLE DYNAMIC COUPLING OR DISTURBANCE EFFECTS ON THIS CONFIGURATION EXCEPT FROM FLUID SURFACE DISTORTION RCS MUST OPERATE OVER ENTIRE PERIOD OF TRANSFER ORBITER AT STANDOFF DURING TRANSFER OPERATIONS	FEW DISTURBANCE FACTORS DURING TRANSFER INITIAL FILLING OF TANK MAY WET SCREWS WHICH TRAP VAPOR GIVING ERRONEOUS READING OF LOAD
DEPRESSURIZATION	FAILURE OF TANK OR CIS/RNS VENT VALVE TO RESEAT CAUSING LOSS OF PRESSURE 1. VENTING IN ROTATING PLANE OF ICE CRYSTAL FORMATION WHICH WILL CONTAMINATE THE ORBITER 2. PROPELLANT TANK MODULE CANNOT BE RETURNED IN CARGO BAY WITH PRESSURE 14.7 PSI 3. BECAUSE OF CG CONDITIONS THE CIS MAY VENT TWO PHASE FLOW	FAILURE OF CIS/RNS VENT VALVES IN OPEN POSITION WILL CAUSE LOSS OF MISSION 1. ORBITER RETRIEVAL OF PROPELLANT TANK MODULE MUST WAIT UNTIL CLOUD OF ICE CRYSTALS DISSIPATE 2. FAILURE OF PROPELLANT TANK MODULE VENT VALVE IN OPEN POSITION WITH PRESSURE LOSS BELOW 14.7 PSI MUST NOT BE RETURNED IN CARGO BAY UNTIL REPAIRED	VENTING OF THE SYSTEM CAUSED BY SYSTEM FAILURE WOULD GIVE POSSIBLE TIME PHASE FLOW OUT THE VENT A. THERMODYNAMIC VENT CONTROL FAILURE B. AREA CONTAMINATION FROM VENTED FLUIDS C. ORBITER MUST WAIT TO RETRIEVE THE PROPELLANT TANK MODULE DUE TO THE ABOVE
TERMINATE ACCELERATION OR DESPIN	POTENTIAL INSTABILITY DUE TO RCS/DYNAMICS/SLOSHING INTERACTION FAILURE DURING EMERGENCY TERMINATION OF OPERATION MAY ACCELERATE THE HAZARD	POSSIBLE INSTABILITY FROM ANY RCS ACTION BECAUSE OF PROPELLANTS SLOSHING/REACTION TO THRUST TERMINATION N.A.	N.A. N.A.

Table 6.5.4-1 (Continued)

OPERATION	CONCEPT B	CONCEPT C	CONCEPT D
	FAILURE OF RCS SUCH THAT DESPIN IS IMPOSSIBLE IS A CONSIDERATION	LESS REDUNDANCY IN THIS CONCEPT COULD CAUSE LOSS OR WEAR-OUT OF RCS	N.A.
CHECKOUT	SYSTEMS COULD BE MONITORED BY ORBITER DATA MANAGEMENT SYSTEM	LOSS OF COMMUNICATION IS A POTENTIAL HAZARD IN THE REMOTE AUTOMATIC MODE	REQUIRES MORE AUTOMATIC FUNCTIONS FOR MONITORING SYSTEM LOSS OF COMMUNICATION IN AUTOMATIC MODE A POTENTIAL HAZARD
REDOCK ORBITER TO PROPELLANT TANK MODULE	N.A.	HARD DOCK 1. POTENTIAL IMPACT 2. DISTURBANCES COULD BE GENERATED IN CIS/RNS	HARD DOCK 1. POTENTIAL IMPACT 2. DISTURBANCES COULD BE GENERATED IN CIS/RNS
UNDOCK PROPELLANT TANK MODULE FROM CIS/RNS	SAME	SAME	SAME
SECURE	PROPELLANT TANK MODULE ROTATED INTO ORBITER CARGO BAY 1. ATTACH POINTS AT CARGO BAY INTERFACE MUST LOCK 2. ROTATIONAL MECHANISM REQUIRES LATCHING FOR SAFETY DURING DEORBIT	SAME	SAME

Table 6.5.4-1 (Continued)

Safety Considerations for Evaluating
~~Propellant Logistic Elements~~
Number of Failure Effects on Crew

CONCEPT B	CONCEPT C	CONCEPT D
1. CREW EXPOSED TO THE EFFECTS OF A FAILURE THROUGHOUT THE ENTIRE DEPLOYMENT, DOCKING, TRANSFER AND RETRIEVAL PROCESS: A. FAILURE OF THE TANK DEPLOYMENT MECHANISM IN INTERMEDIATE POSITION REQUIRING EMERGENCY SEPARATION OF THE DEVICE. B. HARD DOCK COULD CAUSE IMPACT DAMAGE IF RCS INADVERTENTLY OPERATES AT DOCKING C. CAPTURE BUT NOT RIGIDIZED DURING MISSED DOCKING ATTEMPT COULD CAUSE STRUCTURAL DAMAGE, SLOSHING, AND LOSS OF CONTROL D. ANY CATASTROPHIC FAILURE DURING FLUID TRANSFER PRODUCING AN EXPLOSION 1. ORBITER CONTROL DAMAGE FROM FRAGMENTATION 2. OPEN OR CAUSE FRAGMENTS TO PENETRATE THE PRESSURE HULL 3. CAUSE LOSS OF PRESSURE IN THE PROPELLANT TANK MODULE WHICH CAUSES EXPLOSIVE POTENTIAL DURING DEORBIT E. DISTURBANCES MAY AFFECT THE CREW ADVERSELY F. ANY FAILURE CAUSING LOSS OF CAPABILITY TO DESPIN OR TERMINATE SPINUP RCS THRUST G. FAILURES CAUSING HANGUP AT UNDOCKING GIVES POTENTIAL FOR IMPACT AND LOSS OF VEHICLE CONTROL H. POTENTIAL HAZARD IN FAILURE TO MAINTAIN CG ALIGNMENT CAUSING SHIFT OF GRAVITY FORCE ON THE CREW I. LOSS OF ATTITUDE CONTROL A POTENTIAL HAZARD DURING ROTATION FOR PROPELLANT SETTLING	1. CREW IS EXPOSED TO THE EFFECTS OF A FAILURE DURING DEPLOYMENT, DOCKING AND RETRIEVAL PROCESS ONLY. THESE ARE ESSENTIALLY THE SAME AS CONCEPT B, ITEMS A, B, C, G, & K. 2. CREW WILL BE AT STANDOFF POSITION AND NOT SUBJECTED TO ANY FAILURES DURING FLUID TRANSFER OPERATIONS	1. SAME AS CONCEPT C

Table 6.5.4-2

CONCEPT B	CONCEPT C	CONCEPT D
J. LEAKAGE WHICH CAUSES ICE CRYSTAL FORMATION IN THE TRANSFER AREA REDUCES CREW CAPABILITY DURING OPERATION K. IMPACT RISK DURING STOWING OF EMPTY TANK MODULE IN CARGO BAY IF MECHANISM IS FAILED AND NOT NOTED		

Table 6.5.4-2 (Continued)

Safety Considerations for Evaluating ~~Propellant Logistic Elements~~ Number of Failure Effects on Structure

CONCEPT B	CONCEPT C	CONCEPT D
a. Disturbances create stressing between the elements of the configuration; i.e., orbiter, propellant tank module and CIS/RNS.	a. Disturbance stressing of structure reduced by the configuration.	a. Same as Concept C
b. Failure of the deployment mechanism during rotational acceleration gives potential for impact with the orbiter.	b. N/A	b. N/A
c. Excessive docking impact could fail the deployment mechanism.	c. Same as Concept B.	c. Same as Concept B.
d. Misalignment at docking could cause damage to the line interconnect fixture precluding their operation.	d. Same as Concept B.	d. Same as Concept B.
e. Catastrophic failure from explosion could destroy the configuration: Gas Generator or Heat Exchanger failure	e. Same as Concept B.	e. Same as Concept B.
f. Failure of the RCS to shut off could cause potential failure of the structure during spinup, from excessive spin.	f. Leakage during undocking the tank from the deployment mechanism could cause spill into the cargo bay area.	f. Same as Concept C.
g. Hangup of capture latches upon separation attempt causes structural damage.	g. Same as Concept B.	g. Same as Concept B.
h. Failure of the line interconnect fixture rigidizing probe to release after derigidizing could tear the fixture or damage connectors.	h. Same as Concept B.	h. Same as Concept B.

Table 6.5.4-3

Safety Considerations for Evaluating
Propellant Logistic Elements
Number of Failure Effects on Structure (Continued)

CONCEPT B	CONCEPT C	CONCEPT D
1. Failure of liquid/vapor interface control.	1. This concept provides good potential for liquid/vapor interface control.	1. The development risks in this system preclude hazard determinations and is presently assessed as having greater effect on the structure than Concept C.

Table 6.5.4-3 (Continued)

Safety Considerations for Evaluating Propellant Logistic Elements
Crew Exposure to Risks During Normal Operations

CONCEPT B	CONCEPT C	CONCEPT D
Because of the attachment of the orbiter, tank module and CIS/RNS the time the crew is exposed to transfer risks is greatest during rotational acceleration. Other exposures to risk are essentially the same for Concepts C and D.	Crew not exposed to risk during linear acceleration as the orbiter is at standoff.	Same as Concept C.

Table 6.5.4-4

Safety Considerations for Evaluating Propellant Logistic Elements Attitude Control Capability of Total Configuration

CONCEPT B	CONCEPT C	CONCEPT D
a. Because of the ullage location in this configuration (CG falls inside the CIS/RNS tanks) the two-phase flow through the vent return line may cause fluid surface distortion and sloshing. This could cause attitude control problems.	a. This concept does not have an ullage problem and should provide less disturbances than Concept B.	a. Since attitude control is not a factor in propellant orientation to the transfer pumps this concept has few disturbance factors.
b. Mass leakage, uncontrolled venting, or an intermittent RCS thrust in an adverse plane could cause configuration wobble, dynamic instability and control could be lost.	b. Same as Concept B.	b. Mass leakage, uncontrolled venting or an intermittent RCS thrust in an adverse plane could be expected to spin the configuration
c. Failure of the undocking attempt to make a clean separation, where the vehicles are still captured but not rigidized could lead to loss of vehicle control or structural damage.	c. Same as Concept B.	c. Same as Concept B.
	d. Long duration of thrusting for propellant settling could wear the RCS nozzles, reducing the capability to maintain desired vehicle control.	

Table 6.5.4-5

Safety Considerations for Evaluating Propellant Logistic Elements Impact Control

CONCEPT B	CONCEPT C	CONCEPT D
These concepts have the same impact potential during deployment, docking and retrieval.		
a. This concept has impact potential in the event the deployment mechanism should fail during spinup or spindown. Impact is between the CIS/RNS/tank module and the orbiter. b. Involves docking and undocking one time.	a. This concept has two hard docks and two undocking operations which directly relate to impact potential increase.	a. Same as Concept C.

Table 6.5.4-6

Safety Considerations for Evaluating
Propellant Logistic Elements
Man-Compatibility - CIS/RNS

CONCEPT B	CONCEPT C	CONCEPT D
In all operating modes the CIS/RNS will be man rated, when operating with the orbiter attached.	The CIS/RNS will be man rated.	Same as Concept C.

Table 6.5.4-7

Safety Considerations for Evaluating Propellant Logistic Elements
Man-Compatibility - Propellant Tank Module

CONCEPT B	CONCEPT C	CONCEPT D
When used in the CIS/RNS configuration with orbiter attached the propellant tank module must be man rated.	With the orbiter not attached in this configuration, the requirement for man rating all propellant tank module systems would not exist. As long as the safety factors for the module are met for those conditions of cargo bay operation, subsystems activated when the orbiter is at standoff conceivably may not be man rated.	Same as Concept C.

Table 6.5.4-8

Safety Considerations for Evaluating Propellant Logistic Elements Communication Control

CONCEPT B	CONCEPT C	CONCEPT D
In the rotational mode of operation for propellant settling the configuration may have intermittent blackout of communications due to loss of antenna orientation.	Orientation of antenna is not a problem causing blackout of communications. Failure of the ability of the orbiter to communicate with the configuration when the CIS/RNS/tank module is operating in the automatic mode could negate the command override capability of the orbiter.	Same as Concept C.

Table 6.5.4-9

Safety Considerations for Evaluating
Propellant Logistic Elements
Leakage Control

CONCEPT B	CONCEPT C	CONCEPT D
The leakage control factors during deployment, docking and retrieval operations are the same for Concepts B, C, and D.		
Disturbances may cause structural deflection in this concept causing leakage at the CIS/RNS/tank module interface. Major leakage or line rupture to disturbance, could cause the transfer area to be enveloped in an ice crystal cloud.	Major leakage or line rupture may cause disturbance to the vehicle control. Linear acceleration control would move the configuration away from but not out of the ice crystal cloud relative to the point in space the leak occurred. (Cloud could spread at rate up to 300 mph.)	Major leakage or line rupture could cause the transfer area to be enveloped in an ice crystal cloud.

Table 6.5.4-10

6.6 SAFETY EVALUATION OF A MODULAR CONCEPT - CIS/RNS TYPE

6.6.1 Introduction

A modular concept of the CIS/RNS type was evaluated for comparative purposes to a CIS/RNS fluid transfer concept. The objective was to evaluate a modular concept on the same basis as used for the four CIS/RNS fluid transfer concepts contained in Paragraph 6.5. This concept required transfer of propellant tank modules rather than fluid transfer between elements.

6.6.2 Summary of Results

The safety evaluation of the conceptual modular element indicated it to be competitive with the CIS/RNS (non-Modular Configuration) from a safety viewpoint. This safety viewpoint may change when a firm configuration of the Modular concept is developed, as the evaluation was made on a purely conceptual basis. See Table 6.6.2-1 for overall rating.

6.6.3 Candidate Concept

The modular concept evaluated from a safety viewpoint is schematically portrayed in Figure 6.6.3-1. This concept involves deployment of the propellant tank module out of the orbiter cargo bay at a stationkeeping distance from the modular structure. The tank is docked to a rotable docking fixture structure which is then rotated parallel with the centerline and locked in place.

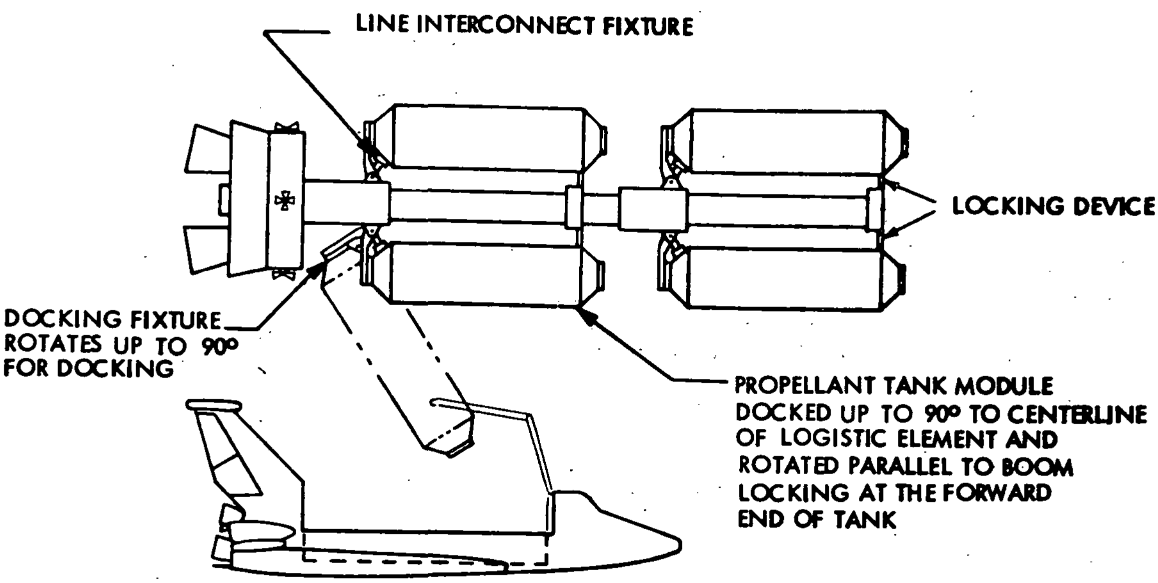


Figure 6.6.3-1 Typical Modular Transfer Concept

EVALUATION FOR MODULAR CONCEPT
PROPELLANT LOGISTIC ELEMENTS

SAFETY CONSIDERATION	CONFIGURATION MODULAR CONCEPT CIS/RNS TYPE
NUMBER OF CRITICAL OPERATIONS	3
NUMBER OF FAILURE EFFORTS:	
A. ON CREW	1
B. ON STRUCTURE	2
CREW EXPOSURE TO RISK DURING NORMAL OPERATIONS	1
ATTITUDE CONTROL CAPABILITY OF TOTAL CONFIGURATION	1
IMPACT CONTROL	1
MAN-COMPATIBILITY	NOT APPLICABLE
COMMUNICATION CONTROL	1
LEAKAGE CONTROL	2
TOTAL	12
OVERALL RATING	1

TABLE 6.6.2-1

6.6.4 Safety Considerations for Evaluating Propellant Logistic Elements

a. Number of Critical Operations - This evaluates the critical operations covering the orbital operations from the time the orbiter arrives with the propellant tank module through deployment, docking, transfer and retrieval.

b. Number of Failure Affects

1. On the Crew: This item evaluates the major potential hazards to the crew as a result of the affects of a failure during deployment, docking, transfer, and retrieval.

2. Hazards to the Structure: This item evaluates the major potential hazards to the structure as a result of the affects of a failure during a critical operation.

c. Crew Exposure to Visits during Normal Operations - This evaluation item covers the risks associated with a time line during which the propellant logistic elements are engaged in fluid transfer.

d. Attitude Control Capability of Total Configuration - This evaluation item covers those aspects of the configuration dealing with control of disturbances, structural interaction and RCS operation.

e. Impact Control - This evaluation item covers those operations during deployment, docking, transfer and retrieval which are directly relatable to potential impact conditions.

f. **Man-Compatibility**

1. Modular Element: This evaluation item covers the requirements, or lack thereof, of man-rating as it relates to its functioning in relation to the Orbiter.

2. Propellant Tank Module: This evaluation item covers the requirements or lack thereof, or man-rating of the tank module as it relates to its functioning in relation to the Orbiter and Modular element.

g. Communication Control - This item evaluates the continuity of maintaining communications in the operational mode during transfer.

h. Leakage Control - This evaluation item covers the major factors contributing to leakage of the configuration.

Data supporting these considerations is contained in Tables 6.6.4-1 through 6.6.4-8.

TABLE 6.6.4-1 SAFETY CONDITIONS FOR EVALUATING PROPELLANT LOGISTIC ELEMENTS NUMBER OF CRITICAL OPERATIONS

OPERATION	MODULAR CONCEPT CIS/RNS TYPE
Rendezvous	Same as CIS operations with Orbiter.
Maneuver	1. Hazards of radiation from engine on RNS affect maneuvering pattern.
Deploy Module	1. Impact hazards where manipulators are used alone to deploy module out of cargo bay. This increases proportional to the number of tank modules used by the logistic element.
	2. Requires disconnect of line interconnect fixture in cargo bay providing potential leakage. This increases proportional to the number of tank modules used by the logistic element.
	3. Potential for mechanism failure during deployment. This increases proportional to the number of tank modules used by the logistic element.
Station Keep	Greater total station keeping time required proportional tot he number of propellant modules required.
Dock & Rigidize	1. Potential impact from disturbances increased due to number of dockings.
	2. Impact from loss of deployment aids, over control and off center docking approach. Damage potential from loss of manipulator and docking aids increases due to number of dockings.
	3. Impact from configuration rotation increases with number of dockings.
	4. Failure of mechanism to align docked tanks with boom and capture for receiving.

TABLE 6.6.4-1 SAFETY CONDITIONS FOR EVALUATING PROPELLANT LOGISTIC ELEMENTS NUMBER OF CRITICAL OPERATIONS (CONT.)

OPERATION	MODULAR CONCEPT CIS/RNS TYPE
Dock & Rigidize (Cont.)	5. Number of dockings required equal to number of tanks required-increases impact potential.
Line Interconnect Fixtures Rigidized	Potential for hazard generation increases with number of connections required.
Line Connections Made	Requires more connections as tank modules are added. Hazards increase.
Transfer	5. Not Applicable
Line Draining	Not applicable until after logistic module mission completion. Locked up lines without relief could cause rupture.
Depressurization	1. Not applicable until completion of mission. Prior to earth return of tank module pressurization must be verified to be at least 14.7 psi.
Terminate Acceleration or Despin	1. Not applicable
Propellant Settling	No propellants transferred until used.
Pressurization	1. This operation is delayed until activation for mission operation.
Childown	1. This is delayed until logistics module is activated for mission use.
Transfer	1. Fluid not transferred.

TABLE 6.6.4-1 SAFETY CONDITIONS FOR EVALUATING PROPELLANT LOGISTIC ELEMENTS NUMBER OF CRITICAL OPERATIONS (CONT.)

OPERATION	MODULAR CONCEPT CIS/RNS TYPE
Checkout	1. Loss of communication is a potential hazard due to remote operation and number of individual tank modules to be monitored. 2. Maneuvers for visual checkout could lead to impact hazard - more observations increase hazard potential. 3. Number of checkouts proportional to number of tanks docked.
Secure	Greater number of securing operations required proportional to number of tanks docked.

Table 6.6.4-2 Safety Consideration for Evaluating Propellant Logistic Elements

Number of Failure Effects on Crew

Modular Concept CIS/RNS Type
1. Impact hazard causing tank failure during deployment could cause more spill causing ice crystal formation in Orbiter area, reducing crew effectivity. 2. Failure of line interconnect during demating from the cargo bay interface, causing leakage, causes same effect as (1) above. 3. Deployment mechanism failure in intermediate or deployed mode a potential hazard to crew if it cannot be jettisoned. 4. Docking aids failure causing impact and configuration rotation may have latent effect during reentry from possible cracking of the heat shield. 5. Undocking attempt before capture latch release, coupled with disturbance could cause configuration rotation resulting in impact with Orbiter heat shield. Effect on crew is at reentry.

Table 6.6.4-3 SAFETY CONSIDERATIONS FOR EVALUATING PROPELLANT LOGISTIC ELEMENTS

Number of Failure Effects on Structure

Modular Concept CIS/RNS Type
1. Impact during propellant tank deployment with the cargo bay walls or doors from manipulator failures. 2. Leakage from line interconnect failure in cargo bay could cause latent explosive effect during re-entry if not noted. 3. Jettisoning of failed deployment mechanism could possibly result in damage to cargo bay doors or heat shield. 4. Undocking attempt before capture latch release, coupled with disturbances could cause configuration rotation resulting in impact with orbiter. 5. Missed docking due to misalignment could damage docking mechanism or line interconnect fixtures of the modular structure. 6. Failure of the ring docking mechanism on the modular structure would preclude docking of propellant tank module thereto. 7. Failure of locking latch during linear acceleration of mission may cause structural damage due to moment created. 8. Catastrophic explosion of a module on the modular structure could possibly destroy the entire configuration. Explosion relates to a gas generator or heat exchanger failure.

Table 6.6.4-4 Safety Consideration for Evaluating Propellant Logistic Elements

Crew Exposure to Risks during Normal Operations

Modular Concept CIS/RNS Type
1. Crew exposure is limited to the exposure time during attachment of the propellant tank modules and retrieval after mission accomplishment. The crew is not involved during module operation.

Table 6.6.4-5 SAFETY CONSIDERATION FOR EVALUATING PROPELLANT LOGISTIC ELEMENTS

Attitude Control Capability of Total Configuration

Modular Concept CIS/RNS Type
1. The CG location which influences impact caused rotation, can be controlled by preplanned docking of propellant tank modules at docking rings on the modular structure. 2. Disturbance factors should be reduced as propellants are not transferred causing potential sloshing. 3. Soft docking of propellant tank modules reduces sloshing hazard.

Table 6.6.4-6 Safety Consideration for Evaluating Propellant Logistic Element

Impact Control

Modular Concept CIS/RNS Type
1. Impact hazards where manipulators alone are used to deploy a tank module out of the cargo bay. These impact potentials increase proportional to the number of tank modules deployed for the modular configuration. 2. Potential impact from disturbances in tank module with the module extended on the manipulators - proportional to number of dockings. 3. Potential impact with the Modular structure, during Orbiter maneuvering for tank emplacement or visual check. 4. Loss of docking aids or TV monitor could cause orientation data to be lost increasing impact potential.

Table 6.6.4-7 Safety Consideration for Evaluating Propellant Logistic Elements

Communication Control

Modular Concept CIS/RNS Type
1. Antenna orientation not a factor. 2. Loss of monitoring data within the Modular structure for operational checkout and automatic control due to configuration complex operations increases communication control hazards for operational use.

Table 6.6.4-8 Safety Consideration for Evaluating Propellant Logistic Elements

Leakage Control

Modular Concept CIS/RNS Type
1. That portion of the concept relating to leakage during Orbiter operations for propellant tank module deployment are related to demating of the line interconnect fixture at the cargo bay interface and impacts during deployment causing leakage into the cargo bay area in the form of snow, ice crystals or ribbons. 2. Leakage on the Modular structure after docking relates to meteoroid impact, impact with space debris and leakage from non rigidization of the line interconnect fixture on the ring docking structure allowing leakage at the QD. 3. Leakage also is a potential hazard should the LO_2/LH_2 line extension bellows fail during extension for hookup.

6.7 SAFETY EVALUATION OF ORBITER TO ORBITER PROPELLANT TRANSFER

6.7.1 Introduction

It can be postulated during the life of the orbital logistics operation, the prime delivery element (Orbiter) may, through an extended mission requirement or other propellant depletion causes, deplete its RCS or OMS propellants to the point that replenishment of its propellant supply is necessary before de-orbit is attempted. The objective is to evaluate conceptual methods for replenishment of propellants to the Orbiter, from a system safety viewpoint. For purposes of this discussion, the NR-176A Model of the Orbiter is used as a baseline configuration.

6.7.2 Summary of Results

The safety evaluation investigated three approaches that were potential candidates. No safety preference was given as to do so would be premature in light of present Orbiter concept considerations. When the design concept is more firm, additional investigation would be required on the configuration if this capability is to be a requirement.

6.7.3 Discussion of Candidate Concepts

For purposes of this discussion the NR-176A Model of the Orbiter is used as a baseline configuration.

The -176A Model is configured with the RCS package attached at the wing tips and at the top of the vertical stabilizer. The OMS is faired into the aft section of the fuselage at the base of the vertical stabilizer. Both the RCS and OMS packages are self contained and use helium pressurant to effect propellant expulsion by use of metal bellows in the propellant tanks. Propellants are different between systems with the RCS using a monopropellant and the OMS using hypergolic propellants. Both the RCS and OMS packages are rigidly attached to the structure such that it would be impractical to try to effect their detachment by EVA. The electrical leads and connections to the packages do not lend themselves to disconnection by QD or EVA.

While many systems could be developed which could accomplish propellant transfer for the RCS and OMS, three approaches appear to reduce EVA requirements and provide the necessary capability for propellant transfer. These are as follows.

a. Provide preplumbed lines into the system from each RCS and OMS tank propellant supply manifold to line interconnect fixtures in the cargo bay which could mate with propellant tank kits provided for the specific transfer operation and could be secured in the cargo bay after transfer by manipulators. See Figure 6.7.3-1.

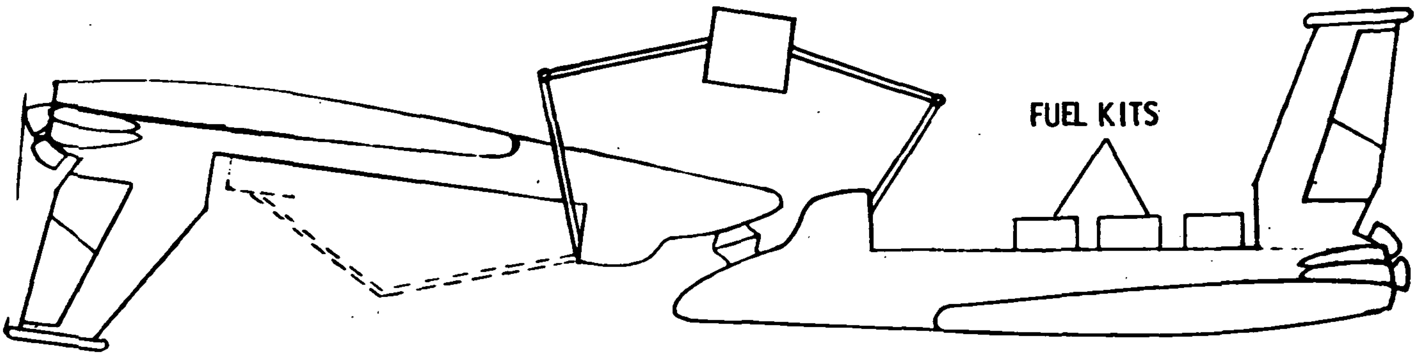


Figure 6.7.3-1 Orbiter to Orbiter Transfer Concept A (Pre- Plumbed System)

b. Utilize the airborne half of the ground fill line attach points to the RCS or OMS tanks and, through use of long flex lines attached to the manipulator and compatible fittings, connect the lines for transfer of propellants from tank kits in the logistic supply orbiter cargo bay. See Figure 6.7.3-2.

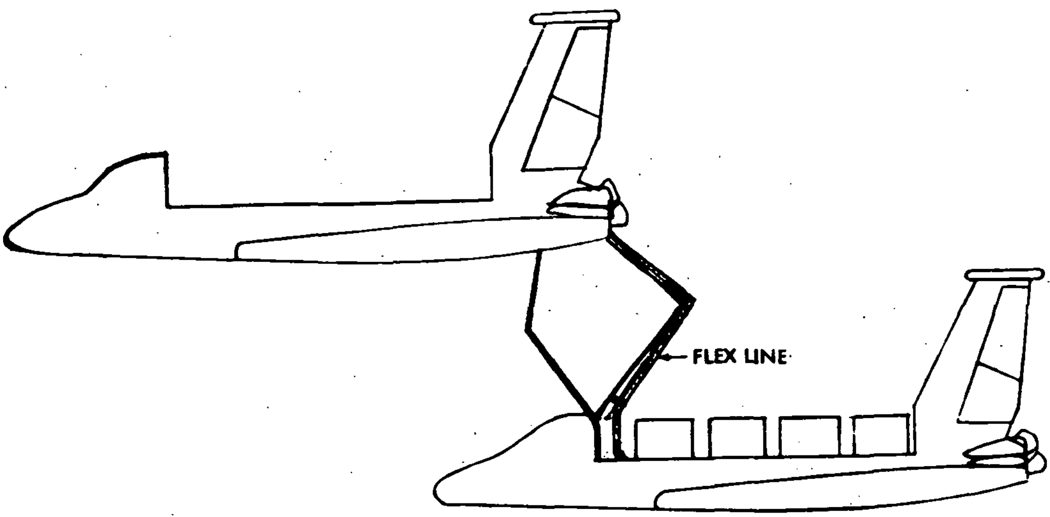


Figure 6.7.3-2 Orbiter to Orbiter Transfer Concept B (Utilize Ground Fill System)

c. Provide the capability for quick release and attachment of the RCS and OMS pods such that package detachment and replacement with a fully fueled package can be effected using manipulators. See Figure 6.7.3-3.

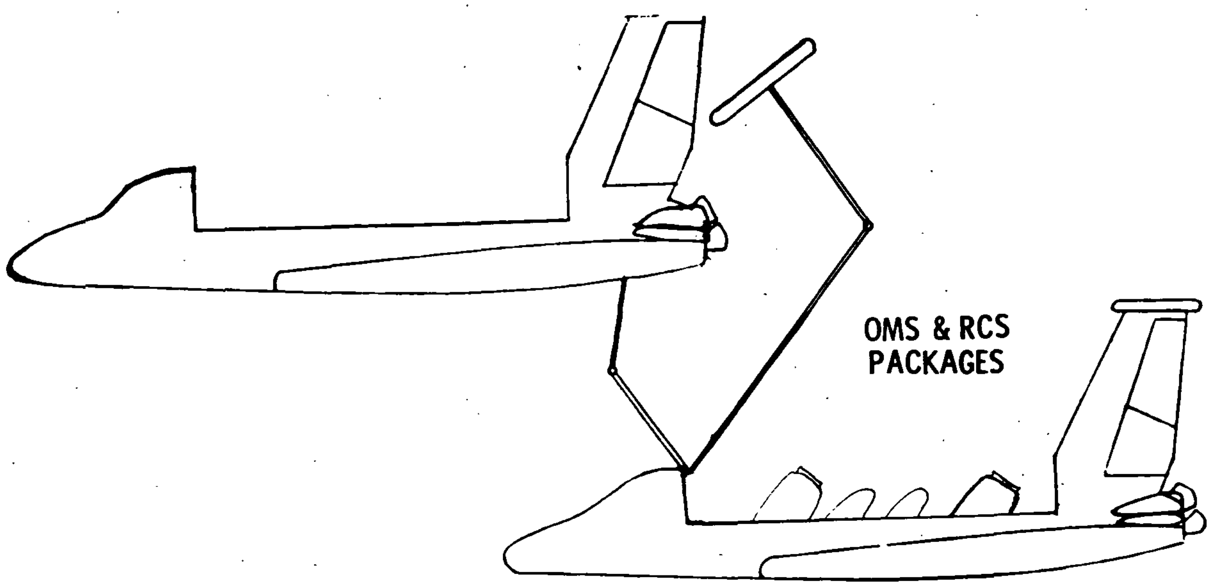


Figure 6.7.3-3 Orbiter to Orbiter Transfer Concept C (Removable OMS & RCS Packages)

6.7.4 Safety Evaluation of Concepts

The Orbiter-to-Orbiter propellant transfer was evaluated for involved operations during the transfer. The evaluation data is contained in Table 6.7.4-1.

From a review of the three approaches no safety preference was made. Approach two seems to eliminate many operations where leakage could occur and uses systems which are existing. The use of long flex lines with problems of attachment, heating and stowing could offset these advantages.

Table 6.7.4-1

Orbiter to Orbiter Propellant Transfer

OPERATION	SYSTEM SAFETY CONSIDERATIONS		
	Approach 1 PRE-PLUMBED SYSTEM	Approach 2 FILL THROUGH GROUND FILL SYSTEM	Approach 3 PROVIDE QD FOR RCS/OMS PKG REPLACEMENT
Maneuver into position with receiver orbiter.	Must be stabilized.	Must be relatively stable.	Must be relatively stable.
Dock	Docking at forward docking port will require docking adaptors to be installed. Impact could cause damage to thermal protective insulation. Soft dock involved because of use of manipulators.	No docking required. Clearance can be provided by one manipulator.	No docking required. Manipulator will attach to Orbiter and provide standoff clearance between vehicles.
Transfer propellant and helium pressurization logistic kits/package.	Manipulators of logistic orbiter must transfer logistic kit from cargo bay to receiver Orbiter's cargo bay. 1. Potential for impact. 2. Transfer from manipulator of 3. one Orbiter to manipulator of receiver Orbiter required. 3. Logistic kits must be positioned in predetermined alignment for line interconnect fixture connection and rigidizing. Option for this with "no docking" is two manipulators provide stability and separation while other manipulators attach to and emplace logistic kit in cargo bay. Loss of manipulator aids would slow operations.	No transfer of kits required between Orbiter cargo bays. No new plumbing required.	When the manipulator has attached to the RCS/OMS package, the QD is released and placed in the cargo bay. A fully fueled package is then moved into position and the package attached by operation of the holddown device for securing and rigidizing. 1. Potential of misalignment of the RCS/OMS thrust line. 2. Potential for damage of thermal protection at the moldline. 3. Potential for impact with the Orbiter wings or vertical stabilizer.

Table 6.7.4-1
Orbiter to Orbiter Propellant Transfer

OPERATION	SYSTEM SAFETY CONSIDERATIONS		
	Approach 1 PRE-PLUMBED SYSTEM	Approach 2 FILL THROUGH GROUND FILL SYSTEM	Approach 3 PROVIDE QD FOR RCS/OMS PKG REPLACEMENT
Accomplish hockup	Line interconnect fixture extends and is rigidized by indexing probes. Misalignment of fixtures. Line connections fail to seal at QD.	Manipulator arm with flex hose attached extends and mates to airborne half of ground fill QD. Requires mating for each type of propellant and helium. EVA in cargo bay of logistic Orbiter may be required for attaching/removing flex lines to manipulator arm. Failure of QD's could cause leakage of caustic or toxic fluid in cargo bay. EVA suit damage from leakage of fluids on suit. Manipulator aid's failure would preclude hookup.	Electrical control circuits would require mating. 1. Misalignment could lead to shorting, grounding or open control lines to the RCS/OMS control system. No fluid lines to attach or no open lines. No spills or leaks. Fewer critical operations.
Transfer propellants	Kit is pressurized to expel propellants or He from kit for purposes of bleeding supply lines. Bleed valve failing open would fail system. Overpressurization could rupture kit. Line interconnect fixture leaks could cause contamination of cargo bay. Failure of kit heater could cause freezing of propellants. Expulsion bellows rupture would terminate operation.	Fluid fills flex line to QD. No bleed necessary. Failure of heater system would result in propellant freezing. Explulsion bellows rupture would terminate operation.	No propellants are transferred by means other than as a complete package.

Table 6.7.4-1

Orbiter to Orbiter Propellant Transfer

OPERATION	SYSTEM SAFETY CONSIDERATIONS		
	Approach 1 PRE-PLUMBED SYSTEM	Approach 2 FILL THROUGH GROUND FILL SYSTEM	Approach 3 PROVIDE QD FOR RCS/OMS PKG REPLACEMENT
Unhook QD's	Not required until safed on earth return.	Manipulator withdraws fill line QD from airborne half of QD each time a transfer is made until all are withdrawn after re-supply. Leakage at QD's could present contamination and toxicity problems.	Not required.
Undock, detach and separate	Undocking is effected at docking adapter mating surface. Explosive separation of adapters provided for emergency use. Manipulators are lowered to cargo bay. Logistic Orbiter separates from receiver Orbiter.	No undocking involved. Manipulators are detached and lowered to cargo bay. Logistic Orbiter separates from receiver Orbiter.	No undocking required. Orbiter separate to standoff distance. Manipulator is detached from the Orbiter and retrieved RCS/OMS packages are placed in position for securing.
Secure	Manipulators must be secured. Receiver Orbiter secures kits for re-entry.	Manipulators secured. Flex lines secured in cargo bay. May require EVA.	Manipulators secured. RCS/OMS packages secured.

7.0 CONCLUSIONS

The System Safety Analysis of In Space Propellant Logistics Operations was performed to determine the recommended safety guidelines for implementing these operations. Several major conclusions have been formulated relative to these operations.

a. In space propellant logistics operations can be performed safely for both the with storage and without storage concepts.

b. Propellant delivery direct to a user without storage is a safer concept than with storage because of the reduction of the number of critical operations.

c. Non-deployment of the propellant tank module from the orbiter cargo bay is the recommended safety concept for propellant transfer to tug-type vehicles.

d. Deployment of a propellant logistic element from the orbiter cargo bay for soft docking to another element should be accomplished with a combination of the manipulator and rotational deployment mechanisms.

e. Modular transfer of propellants to modular users is a recommended concept.

f. Rotational and linear accelerations during fluid transfer are both safe concepts for propellant settling.

g. Fluid transfer from a propellant tank module to a small (tug type) vehicle may be performed safely with the orbiter attached or the orbiter not attached.

h. Fluid transfer from a propellant tank module to a large (LSF, CIS or RNS) vehicle should be accomplished with the orbiter not attached.

i. The effect of disturbances resulting from fluid instability and their effect on vehicle control systems during propellant logistics operations is a potential residual hazard.

j. Large propellant leaks in space which solidify in the cargo bay will sublime in a few hours if the bay is oriented for maximum heating.

k. Propellant leakage or venting in the cargo bay during deorbit operations is a potential residual hazard.

l. Propellant logistics elements can be returned to earth safely in the orbiter cargo bay if propellant leakage is within specification and if the pressure relief capability provided for the tanks allows for a rapid change of the liquid residual propellants to a gas without exceeding acceptable tank pressures.

m. Uniformity and commonality of interfaces for docking, stowing and transfer operations between interfacing propellant logistics elements (including orbiter) is required.

8.0 ADDITIONAL STUDY EFFORT RECOMMENDED

System Safety analyses have identified areas requiring efforts which are beyond the scope of the study. Because of the potential hazards associated with these areas, resolution should be considered prior to space shuttle/propellant logistic element integration.

8.1 DYNAMIC CONTROL OF VARIOUS MATED CONFIGURATIONS

Disturbances such as sloshing, impact, fluid surface distortion, are present in propellant logistic operations. The effect of these disturbances acting on various elements or combinations of docked elements, cannot be fully investigated without study of the coupling effects of the elements' structural dynamics and RCS action when influenced by the disturbances in zero g. A study is required to provide visibility on the sensitivity of these variables during critical propellant logistic operations.

8.2 ZERO "G" LEAK DETECTION

Zero g leak detection devices and sensing techniques should be developed for use with orbital propellant logistic operations.

8.3 LOW THRUST RCS

A long life low thrust RCS should be developed for safe linear acceleration propellant settling operations.

8.4 ZERO "G" PROPELLANT GAUGING

Random orientation of propellants (LH_2 SH_2, LO_2) in zero g requires study of quantity gauging techniques for propellant logistic tanks in orbital use. The potential loss of tank thermal protective environment causing hot spots makes this measurement a critical item for earth return of the tank module in the orbiter cargo bay.

8.5 VAPORIZATION OF RESIDUAL PROPELLANTS

Sloshing of residual propellants against a warm wall of a tank in the cargo bay during deorbit and landing could cause the fluid to flash to a vapor. A transient analysis which considers the parameters influencing residual propellants in the tank should be conducted. The investigation should provide design considerations relating to vent sizing, tank volumes and residual propellant quantities, as a function of heat inputs anticipated for various insulation efficiencies.

APPENDIX A

REPRESENTATIVE ORBITAL PROPELLANT LOGISTIC OPERATIONS AND FUNCTIONAL FLOW DIAGRAMS

INTRODUCTION

Operations and functions of the Representative Orbital Propellant Logistic concept were developed for the concept baseline initially and as variations by the tug sharing delivery functions was introduced the delta operations and functions were added. These delta operations and functions are coded with a letter A after the applicable functional flow diagram number.

With the introduction of the ESS variation as another concept for delivery of large propellant tanks to orbit in support of CIS/RNS, the functions were described but the operations were used as presented in the NR Phase B Final Report of the ESS/Reusable Space Shuttle Booster under Contract NAS9-10960 and are not re-written in this report. The functional flow diagrams for the ESS variation are coded by a letter B.

These operations with functional flow diagrams were used in supporting the FMEA's and hazard analyses conducted during the study.

Operations

The booster is not considered in its role, as a part of this safety study as only orbital operations are addressed, except where any unique hazard may be identified through interface with the handling, transfer, transport or storage of orbital propellant elements.

Where there is a possibility of major impact to the propellant delivery elements, both booster and orbiter operations are included and may reflect some redundancy with other studies.

1. FFD 2.0 Perform Assembly and Launch to Orbit

   The general functions of FFD 2.0, associated with this Safety Study, start with the attainment of standby status.

   Attainment of standby status includes all requirements necessary to place the space shuttle and propellant module in a mode that will permit the start of launch countdown. All vehicle systems will be brought to a flight-ready configuration and maintained in this mode. Control of access to the launch pad area and vehicle will be established. Status monitoring will be via the data bus and support equipment.

Selected vehicle subsystems will be powered down to permit electrical checkout and subsequent connection of ordnance interface connectors.

Support equipment and propellant storage areas will be prepared and brought to a launch ready configuration. Propellant transfer systems for shuttle and propellant module, pressurant systems and equipment valve statusing will be placed in a launch ready configuration.

After ordnance connection, servicing of JP and LH_2 tanks and line conditioning, the LH_2 system for the shuttle and propellant module or payload will be monitored until launch.

Rigid pad and vehicle control is implemented prior to these operations and maintained because of the hazardous nature of the shuttle and module propellant tank atmospheres.

Perishable items, payload and hazardous cargo will be loaded (food, servicing payload nitrogen tanks, and storage of UDMH or N_2O_4 containers) and placed in a standby mode.

During this period, should a decision be made to change the payload, interfaces will be disconnected to prevent interference with the payload handling device and payload transfer device, except those necessary to purge and inert the propellant module tank of gaseous hydrogen. Once inerted the remaining disconnects are removed, the payload is extracted from the cargo bay and lowered to a waiting payload transporter for return to the payload handling facility. Emplacement of the new payload will require the same basic devices and a post checkout will be conducted via the Data and Control Management System (DCM) to verify compatibility of the new payload and orbiter interfaces. Update of mission software is made to update the flight program in the DCM and verify same.

Perform Launch Operations

Launch operations begin with propellant loading. The launch pad area will be under access control and cleared during this period. An automated system capable of contingency pause and revert capability will accomplish chilldown of transfer lines and tankage to the shuttle, propellant module or other payload propulsive stage, venting, transfer of propellants, replenishment and propellant loading termination.

After chilldown, simultaneous loading of liquid oxygen (LO_2) and liquid hydrogen (LH_2) into the booster, orbiter and payload will begin. The first phase of loading will be at a low rate of flow, followed by a high rate of flow. Completion of the propellant loading is accomplished by another low flow rate sequence.

Airborne level-sensing transducers feeding the ground computer system and ground transducers will control the automated loading sequence. Remote control and display capability will monitor propellant loading throughout the countdown.

As soon as single phase conditions are achieved, the fuel cells will be started.

Topping of the propellant tanks of the shuttle and propellant payload will replenish propellants lost in boiloff, at a low flow rate. The topping mode is continued throughout crew and passenger loading until time for pressurization. Termination of replenishment is an integral function of the automated terminal countdown.

The launch vehicles and launch pad service tower will incorporate emergency egress capabilities for the flight crews, passengers, and other service personnel during launch operations.

In addition, the launch facility will provide personnel safing areas to protect the crew, passengers, tower and rescue team personnel from possible hazards.

Perform Launch Countdown and Launch

The flight crew will conduct the launch countdown checklist with each function on the countdown checklist performed in sequence. This includes verifications that all systems are configured for launch, confirmation that all supporting systems are in a go condition, starting of the APU's with switching to vehicle internal power once stable running condition is reached. The checklist also includes verifying the hydraulic system selected actuators and automatic scan of the airborne systems configuration and readiness to launch.

Range safety and mission clearance to launch will be received from the Range Safety Officer and Mission Director, respectively.

The launch program will be initiated by the flight crew, with the launch sequence progressing automatically from this point to liftoff.

Perform Mated Ascent

Mated ascent begins at liftoff of the space shuttle from the launch pad and continues until booster-orbiter separation at staging.

At liftoff, the booster engine thrust vector control (TVC) will activate the DCM, and the auto-sequence preprogrammed maneuver will be commanded to provide for vertical flight to about 100 feet above the tower. Following liftoff, the space shuttle vehicle (SSV) will be aligned for vertical flight until the SSV has risen to approximately 100 feet above the tower.

The roll maneuver will be initiated after the SSV has cleared the launch tower. This maneuver is performed with the vehicle vertical after clearing the umbilical tower and rotates the vehicle to enable a pure pitch maneuver into the azimuth required for the desired initial orbit inclination.

The pitch program is initiated upon completion of the roll maneuver.

The primary functions of the ascent guidance are continuing the pitch program, regulating the thrust of the booster engines, and maintaining the roll and yaw attitude of the vehicle.

Perform Booster/Orbiter Staging

The separation subsystem provides a safe separation capability during mated ascent for both normal and abort initiated conditions. Separation of the orbiter from the booster is performed automatically.

The automatic sequence of the booster vehicle staging will be initiated when the propellant depletion system provides a discrete signal. Sensors installed in the booster oxidizer tankage system will provide the primary discrete signals to initiate the sequence. The LH_2 tankage sensors will provide a backup discrete signal. The output of the sensor excitation and monitor circuitry will be used by the DCM to initiate the staging sequence.

When the propellant depletion discrete signal is issued to the DCM in both the orbiter and booster, they will initiate their respective separation sequences. The inertial attitude of the mated vehicles is maintained by the booster engine TVC.

The hold-down links will be released from the orbiter, and the separation system will thrust the orbiter off the booster.

Achieve Initial Earth Orbit

Ascent trajectory parameters are computed by the GN&C subsystem to provide vehicle attitude, altitude, and velocity information. These ascent parameters are computed up to orbit injection. Main engine TVC commands are generated to maintain the required trajectory and achieve the correct orbit injection conditions. If one engine fails, the ACPS provides roll control while the remaining engine controls the vehicle pitch and yaw.

The orbiter main engines will operate during the ascent trajectory at the nominal power level (NPL) until an axial acceleration of 3g's is reached.

Commands from the GN&C subsystem to the engine control unit (ECU) will reduce thrust to compensate for depleted propellants and maintain axial acceleration until engine cutoff. The ECU maintains the

engine thrust and mixture ratio constant at the command setting throughout engine operation. The thrust vector can be controlled over a range of gimbal angles in both pitch and yaw modes by the main propulsion gimbal actuation system.

Injection maneuvers include engine cutoff which will be initiated by a signal from the GN&C subsystem when the proper velocity is reached. Immediately after the main engine shuts down, the LO_2 and LH_2 prevalves will close. With the engine main valves closed a double seal is provided against tank leakage through the engine. Residual propellant boiloff will be relieved overboard through the on-orbit vent valves (33-35 psia) the first day(s) in orbit. When tank conditions indicate boiloff is complete, the vent isolation valves will be closed to minimize leakage for the remainder of the mission. Propellant tank module venting is relieved overboard. A minimum positive tank pressure will be required to assure structural integrity of any propellant tank in the orbiter or returned to earth in the cargo bay.

The cargo bay doors will be opened to expose the space radiators and prevent buildup of hazardous gasses due to propellant tank module venting.

2. FFD 3.0 Perform Orbital Buildup Operations

The Large Storage Facility (LSF) is in orbit with limited attitude control correction capability and is otherwise passive until additional components are deployed by the orbiter and docked.

Orbital deployment of the equipment module will be via the space shuttle. After attainment of orbit by the orbiter and relative orientation, rendezvous operations will bring the orbiter in close proximity to the LSF docking ring. The equipment module will be deployed from the cargo bay and docked with the LSF. After docking the physical interface will be visually checked from the orbiter by the crew, and simple verification tests will be performed. The orbiter will then separate and the crew will perform a visual inspection from within the orbiter of the external area of the LSF. The orbiter will then back off to a safe standoff distance.

Deployment of the LOX module and activation crew will be initiated after equipment module emplacement.

After initial rendezvous and docking of the LOX module to the LSF, the orbiter crew will verify the external systems mating by visual inspection through the orbiter observation ports. This will be done while docked to the LOX module, during orbiter detach operations from the LOX module, and while in transit to the equipment module for re-docking. The onboard checkout system will be verified operational by the Ground Mission Control and the orbiter crew will enter the equipment module. The crew, after verifying the life support system operation, will perform an internal visual inspection

of the crew compartment, the docking ring and the LOX module and all interfaces between these modules. Recalibration and data verification will be performed as necessary from LSF system monitoring performed by Mission Control during the foregoing initial deployment period, the Onboard Checkout Equipment (OBE) operation and the crew members' observances. The power supply will be recharged and replaced as required. EVA inspection of the complete vehicle will be performed only as a last resort as required by determination of the previous inspection of the orbiter. This inspection and checkout will lead to an OK for first user docking. The crew re-enters the orbiter, the orbiter then detaches from the equipment module and maneuvers to a safe distance for first docking observation.

3. FFD 3.0A Perform Transfer of Mission Payload Delivery Function

During this operation the interaction of the orbiter and tug in support of payload/module delivery is operationally described. The orbiter and tug interface at the 100 nm orbit and have effected rendezvous. The orbiter configuration is readied for deployment operations which can involve deployment of a propellant module, the reusable tug or payload propulsive stage and satellite. The orbiter may transfer Orbit Maneuvering System (OMS) propellant to the deployed reusable tug for the initial mission to rendezvous with the LSF or through a second orbiter flight bring a propellant tank module to the space based tug, dock, and transfer propellant direct by rotational or linear acceleration at 100 nm for initiation of the tug's useful operation. In the case of OMS transfer, the transfer of propellants is made through a transfer system contained within the orbiter, interfacing at disconnects in the cargo bay. Once the space based tug is loaded with propellants, the vehicle is deployed by orbiter manipulators to space. Other payload propulsive stages with their payload are also deployed by the orbiter manipulators. Upon deployment the orbiter translates and separates from the delivery vehicle which could be the space based tug, FW-4S, Agena or Centaur. The payload propulsive stages with satellite are then launched to their respective orbits. After the initial deployment of reusable tugs, the operation becomes one of docking the propellant tank module to the tug and transferring the empty propellant tank module returned by the tug to the orbiter cargo bay.

Upon docking the propellant tank module to the space based tug, the orbiter separates from the tug/propellant tank configuration by translation and maintains a standoff distance from the tug while the tug and module are prepared for automatic remote injection operations to a 262 nm orbit and rendezvous with a target which would be a LSF, to conduct propellant transfer operations.

4. FFD 4.0 Perform Propellant Transfer Operation

Performance of this function starts with orbit and phase change through possible use of two types of phasing - natural or catch-up phasing and high phasing or catch-back. The orbit and phase changing will be accomplished by OMS burn.

The actual rendezvous function starts with the terminal phase initiation (TPI) burn of the OMS which puts the orbiter into an orbit from which terminal phase finalization (TPF) maneuvers occur. The orbiter shall be self-targeting and range and range rate must be obtained by the orbiter itself for TPI and TPF. The rendezvous maneuver operation is assumed to position the orbiter within 1000 feet of the LSF. The LSF is a passive cooperative target.

The orbiter will deploy the propellant module by rotation about the y axis or articulation out of the cargo bay by use of manipulators. While both could accomplish the deployment operation the manipulator concept of the baseline system is used for purposes of this study. The propellant tank module is attached to the manipulator system and with the use of aids (TV, floodlights) the module is moved out of the cargo bay and oriented into a docking position. Movement by translation of the orbiter to the LSF is accomplished to within the effective distance of the manipulator arm at low closing velocities of 0.5 feet/sec. The LSF has been stabilized and aligned for docking attitude with communication and control from Mission Control while surveillance will be provided by the orbiter. Docking will be under control of the orbiter crew.

The propellant tank module is aligned and extended by manipulators to dock with the LSF at the docking port outboard on the LOX tank module. The sequence of operation is alignment and centering, contact of cones between active and passive docking assemblies, capture and latching, pull down and rigidizing by 12 separate docking latches, automatically engaged.

The manipulators are disengaged from the propellant tank module and the orbiter translates away from the LSF to a standby position. The orbiter crew provides surveillance while Mission Control commands the propellant transfer operation sequence which covers retraction of the line interconnect fixture meteoroid shield, rigidizing, rack extension and engagement of electrical connection probes, extension of propellant and system lines and transfer preparation and checkout of equipment module and LSF systems in the remote automatic mode. Propellant tank chilldown is followed by actuation of the LSF ACS to impart a very low spin rate to produce an artificial "G" (about .001g) in the LSF configuration for propellant settling. Chilling and pressurization are accomplished followed by propellant fast fill initially, followed by throttled fill during the latter transfer operation period. When propellant transfer is complete, transfer lines are drained of liquids and the system is depressurized. The ACS is commanded to initiate deceleration which upon accomplish-

ment will return the LSF configuration to a stabilized mode.

The LSF configuration is given a post-transfer checkout and secured by Mission Control while surveillance is provided by the orbiter crew. Once secured, the propellant transfer and system lines of the line interconnect fixture are retracted, the electrical connectors are disengaged and the index probes are derigidized and withdrawn/retracted. The line interconnect fixture meteoroid shield is extended to cover the fixture and the undocking of the propellant tank module can commence. A similar transfer approach between the LSF and user is employed except the user docks instead of the propellant tank module, and at a user port location.

The orbiter translates from its standby position to standoff, with the empty propellant tank module, while the manipulators are attached to the module and undocking is accomplished. The orbiter then translates away from the LSF and returns the empty propellant tank module to the orbiter cargo bay.

5. <u>FFD 4.0A Perform Propellant Transfer Operation (Tug)</u>

Performance of this function starts with orbit and phase change through possible use of two types of phasing: natural or catch-up phasing and high phasing or catch-back. The orbit and phase changing will be accomplished by tug main engines burn. Since the entire operation is accomplished in the automatic mode, communication and control between tug and LSF is exercised by Mission Control.

The actual rendezvous function starts with the terminal phase initiation burn of the main engines which puts the space based tug with propellant tank module payload into an orbit from which terminal phase finalization maneuvers occur. The tug under Mission Control surveillance will accomplish the finalization burn and proceed to hard dock the propellant tank module. This docking concept for the tug employes hard docking with integrated mechanical restraint and access system, contains automatic docking features with radar, sensors, guidance and remote control as the primary mode with manual capability using radar, sensors and visual cues as a backup mode. The docking system is a neuter ring and cone assembly. The tug will assume the active role in docking operations with the LSF.

There are concepts of the tug which include a crew module in the tug configuration. For purposes of this study they are addressed lightly only to indicate representative areas of concern, but otherwise the function remains unmanned.

The tug undocks from the propellant tank module and maneuvers to a user port on the LSF where it hard docks for propellant tank replenishment, under the operation of Mission Control. The docking sequence for both the propellant tank module and the tug are similar and involve alignment and centering, contact of cones between active

and passive docking assemblies, capture and latching, pull down and rigidizing by 12 separate docking latches, automatically engaged.

The sequence for propellant transfer from the propellant tank module into the LSF and from the LSF to the tug are now initiated and controlled by Mission Control. The sequence starts with retraction of the line interconnect fixture meteoroid shield, rack extension and engagement of indexing probes, rigidizing the fixture, engagement of electrical connection probes, extension of propellant and system lines and transfer preparation and checkout of equipment module and LSF systems in the remote automatic mode. Propellant tank chilldown is followed by activation of the LSF ACS to impart a very low spin rate to produce an artificial "g" (about .001g) in the LSF configuration for propellant settling. Chilling and pressurization are accomplished followed by propellant fast fill initially followed by throttled fill during the latter transfer operation period. When propellant transfer is complete, transfer lines are drained of liquids and the system is depressurized. The ACS is commanded to initiate deceleration which, upon accomplishment, has returned the LSF configuration to a stabilized mode.

The LSF configuration is given a post-transfer checkout and secured by Mission Control. Once secured, the propellant transfer and system lines of the line interconnect fixture are retracted, the electrical connectors are disengaged and the index probes are derigidized and withdrawn/retracted. The line interconnect fixture meteoroid shield is extended to cover the fixture and the undocking of the tug can commence.

The tug is first to be undocked from the LSF, translating away from the LSF user port and maneuvering into retrieval position with the propellant tank module where it docks to the outboard docking port of the module under automatic or manual override control from Mission Control. Mission Control then commands undocking at the forward docking section/LOX tank module interface and the tug with empty propellant tank module is translated away from the LSF to prepare for a transfer orbit insertion. Mission Control, coordinating the orbiter propellant tank module re-supply schedule, programs the tug/down module orientation for transfer orbit burn execution and deorbit and phasing change are automatically executed by the IMU and monitored by Mission Control. Terminal phase finalization burns are made to bring the tug into a rendezvous position with the orbiter. Standoff from the orbiter is maintained until the transfer of mission payload delivery functions is again initiated by the orbiter in an iterative re-cycle process.

6. FFD 5.0 Perform Maintenance Operations

Maintenance operations functions will require support from the orbiter involving delivery of the necessary modules containing maintenance equipment and delivery of the maintenance crew. The operations start with initiation of orbit and phase change as is

described in FFD 4.0. The maintenance target is the LSF configuration, however where maintenance on propellant systems of the Space Station is required, the Space Station could be a rendezvous target. For this study the Space Station has been indicated in the function but not addressed specifically. The orbiter shall be capable of self targeting and range and range rate data will be obtained by the orbiter for TPI and TPF with update data from Mission Control. The rendezvous maneuver operation is assumed to position the orbiter within 1000 feet of the LSF which is configured with the equipment module and possibly with a user vehicle such as the tug or CIS. The orbiter docks with the equipment module through use of the docking adaptor and off loads the maintenance crew for minor maintenance operations. The LSF ECLSS is activated in the equipment module and maintenance is conducted therein. Upon completion of the maintenance, the equipment module is deactivated, the crew removed, doors and hatches sealed and the orbiter readied for undocking. Portable life support systems are used as required in these operations. Where major maintenance is to be accomplished and the dwell time is anticipated to be extensive, equipment and crew will be delivered to the LSF and stay in a separate crew module which is delivered by the orbiter.

The crew module is deployed by manipulators on the orbiter and translated to dock at a user docking port. The alternative is docking the crew module to the orbiter docking adaptor and then docking at the user port. The maintenance crew will activate the life support system within the LSF tunnels and equipment module with assistance from Mission Control. Upon achieving a suitable environment within the LSF, the orbiter will either disengage the manipulators or undock from the crew module and separate to a safe distance and station-keep. Upon completion of the maintenance activity, the orbiter will re-dock with the crew module or re-attach the manipulators to the crew module in preparation for undocking.

Where the maintenance activity is extended, the orbiter will undock and transfer down modules such as the propellant tank module into the orbiter cargo bay and proceed to ready itself for return to earth. The crew and crew module would be retrieved in this case in a subsequent orbiter operation.

7. <u>FFD 6.0 Undock, Stow and Deorbit/Land</u>

The functional diagram is presented for information purposes, however the propellant logistic operation for safety study purposes completes with the securing of the module in the orbiter cargo bay. This function starts with undocking of the numerous modules or orbiter for purposes of earth return. The modules are emplaced in the cargo bay by the orbiter manipulators, which through use of manipulator aids are guided into the orbiter cargo bay attach fittings and secured thereto. In the case of the crew module, stowage is such that the personnel transfer port provided in the

cargo bay forward bulkhead is aligned so as to allow engagement of the payload mating ring with the extendable personnel transfer port section. This allows personnel access and egress to the payload or orbiter, respectively.

Automatic provisions are assumed for connection of systems critical to the system being secured such as connection of vent valves to the orbiter vent system or pressurization system connection for module pressurization maintenance. EVA is not considered for routine operations, however in emergency operations EVA may be necessary. All EVA will be conducted by the "buddy system." EVA will be as a "last resort" only, for propellant logistic operations.

After properly stowing the down cargo, manipulators and configuring the orbiter for re-entry, on-orbit phasing and vehicle systems will be monitored by Mission Control and navigational update material will be supplied. Retro maneuvers will be made with OMS engine burn. The orbiter will establish and maintain desired pre-entry conditions and, before the orbiter enters at approximately 400,000 feet, the APU's are started, air breathing engines are deployed, ignited, and maintained in the idle mode. The orbiter enters the approach window at approximately 10 nm from the runway. The orbiter landing is made at approximately 165 knots, braked and taxied to the safing area.

8. FFD 7.0 Perform Mission Abort Operations

Pad abort (prelaunch) mode is confined to the period of crew and passenger loading. It terminates at liftoff. This includes booster and orbiter crew and passenger egress, engine and system deactivation, safing and off loading of propellants and return to standby status.

Booster-orbiter mated ascent abort is based on critical failures requiring early separation. After early staging, the booster performs an ascent to propellant depletion and then cruises to permit recovery at the launch site. The orbiter is boosted in a rocket-powered cruise mode to a preselected landing site. For early separation, launch site or down range recovery may be necessary.

The booster post-separation abort mode may occur during booster cruise or during landing as a result of primary turbojet engine failure. The booster abort mode is to perform an emergency cruise to an alternate site and land.

Orbiter ascent abort is considered for two conditions which are non-critical and critical failures. After failure level is identified, three abort options are available: abort to orbit and complete the mission, abort once around to primary landing site, or abort down range when CONUS landing sites are available. Ground control will aid the orbiter crew in making the abort decision and will coordinate orbiter actions with Air Traffic Control (ATC), the booster and

the landing site.

The orbiter landing abort mode is its one-time-go-around capability or emergency landing with reduced turbojet thrust. With turbojet thrust reduced, emergency landing procedures must be accomplished during the initial approach. For the go-around, a nominal final approach corridor is required before a landing is performed. There is no go-around abort mode available for an unpowered orbiter.

Abort from orbit involves the critical consideration of establishing and maintaining the exact position of the orbiter, the wait time, and availability of the landing site. For the selected landing site, the orbiter performs deorbit and entry maneuvers.

If abort requirements are immediate re-entry, the ground will coordinate re-entry plans with ATC and coordinate rescue plans.

Where the abort from orbit allows the vehicle to remain in orbit for a certain time before re-entry, the ground will assist the orbiter in deorbit targeting to select the best landing site for vehicle and crew return.

If the on-orbit abort precludes re-entry, the ground will coordinate the rescue mission.

9. FFD 8.0 Perform Emergency Rescue Operations

Operations for rescue of crews involved in the Orbital Propellant Logistic Operation relate to those needed to rescue maintenance/checkout crews during LSF buildup, checkout and maintenance. This may involve rescue from: the crew module, equipment module, LSF tunnel area between the crew module and equipment module, or rescue of the crew from a disabled orbiter supporting the manned operation. Each of these cases involves the dispatch of the orbiter to dock with the modules or capture the modules with the manipulators and undock the module containing the crews to be rescued. Where the orbiter is not disabled and is on standby, the orbiter will effect the rescue. Where extended work is being performed and the orbiter has returned to earth, dispatch of another orbiter for the rescue mission will be made by ground control.

10. FFD 9.0 Deactivate Propellant Logistic Element

Operations on the orbiter comprise those functions and activities beginning with termination of flight operations at the end of landing rollout and ending at orbiter readiness for premate checkout.

Major tasks accomplished are post-landing safing and securing operations, hangar operations, storage and ground system maintenance. The propellant tank module safing includes propellant system draining, purging and venting containment prior to removal from the cargo bay. Ordnance systems associated with the module docking system,

if any, will be safed, and upon completion of the orbiter safing process the module will be removed from the cargo bay and re-cycled through the maintenance process.

Functional Flow Diagrams

The functional flow diagrams for the above operations are contained in Figures A-1 through A-22. The functions of the baseline Representative Orbital Propellant Logistic Operations with the tug variation in sharing delivery functions are structured together, because of their integrated functions, in Figures A-1 through A-17.

The ESS variation delivering propellants to the CIS direct involves different operations and is thus not structured with the orbiter tug functions. The functions of the ESS variation are contained in Figures A-18 through A-22.

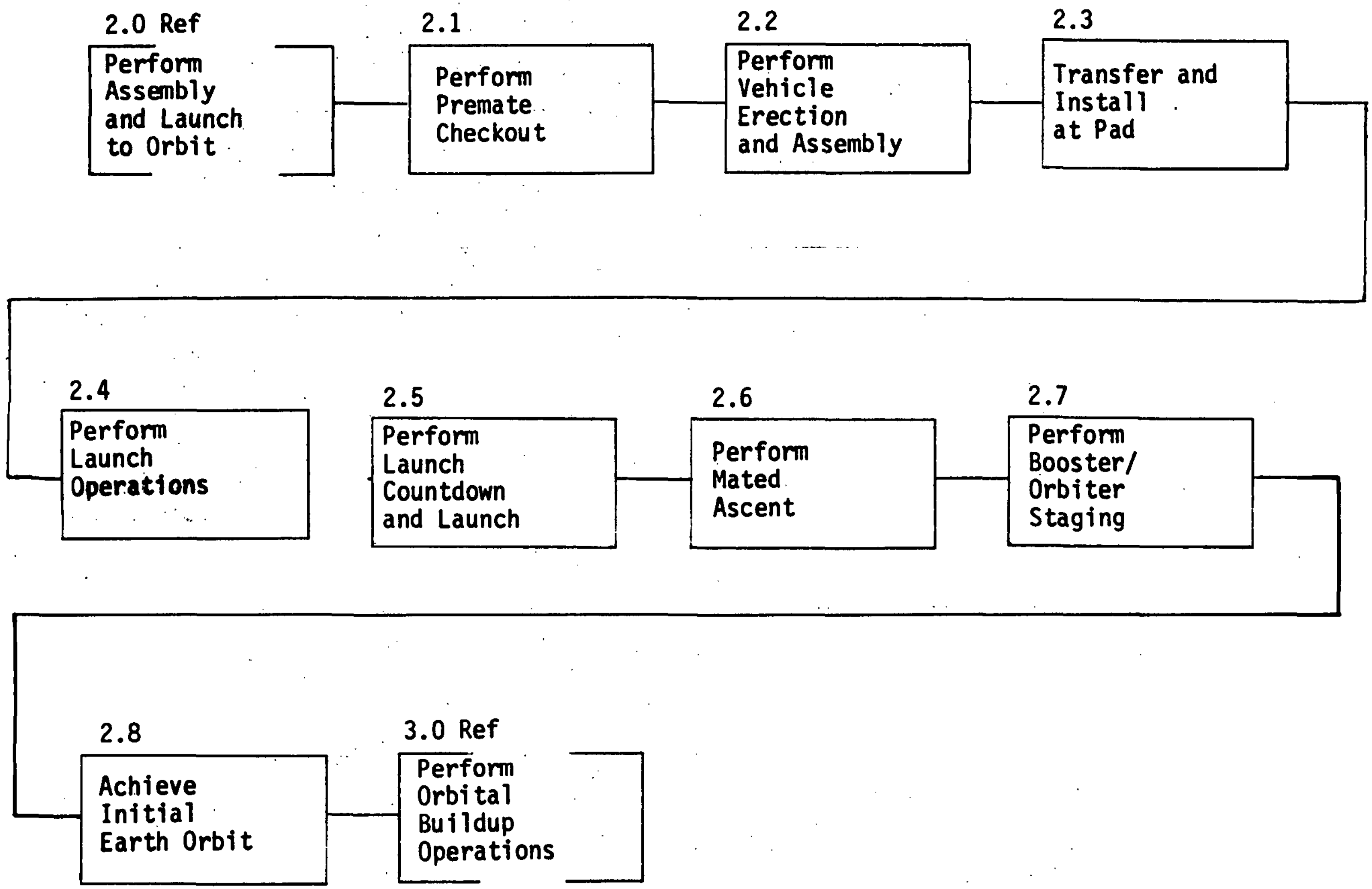


Figure A-1 Perform Assembly and Launch to Orbit (Shuttle/Propellant Module)

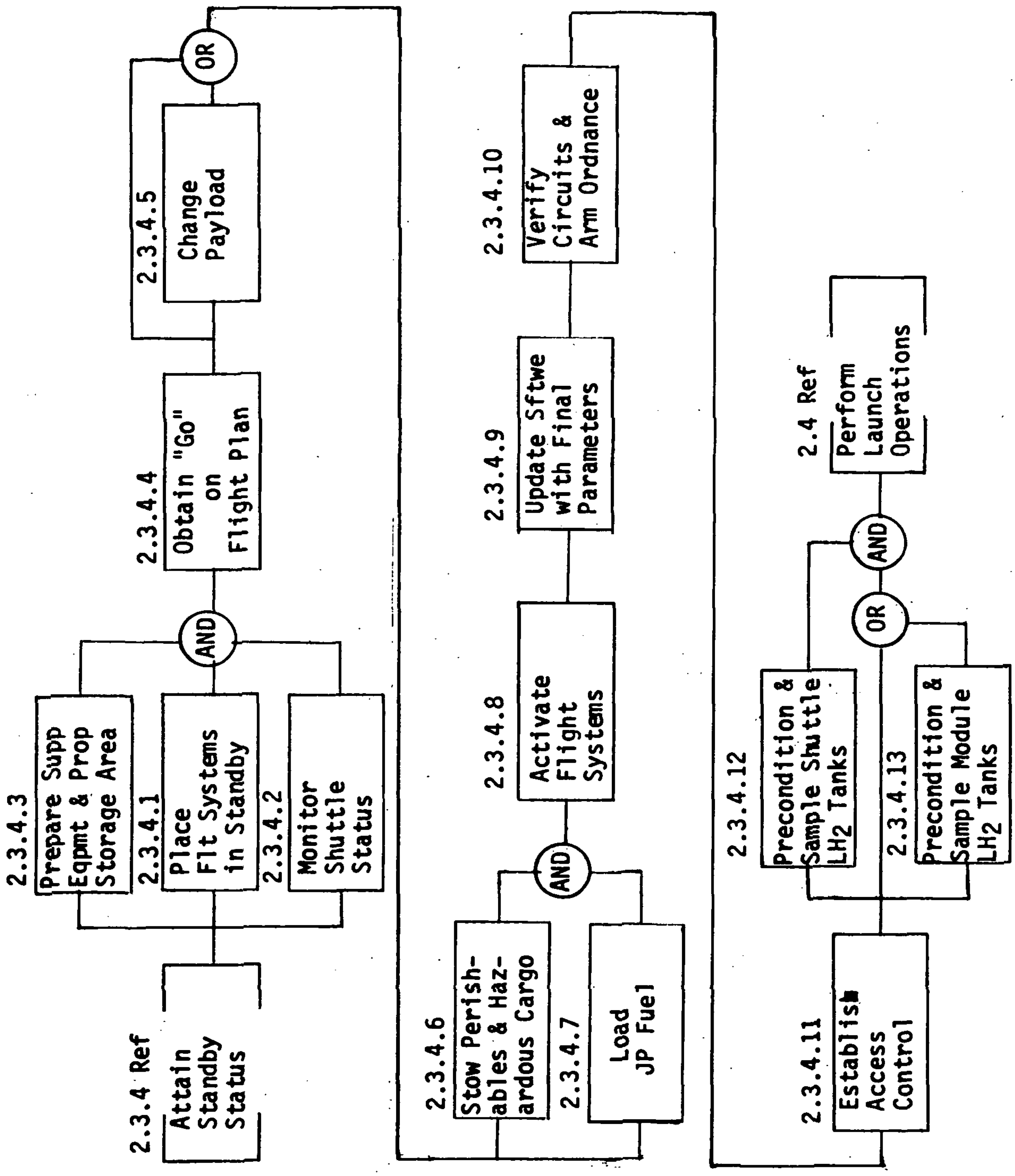


Figure A-2 Attain Standby Status

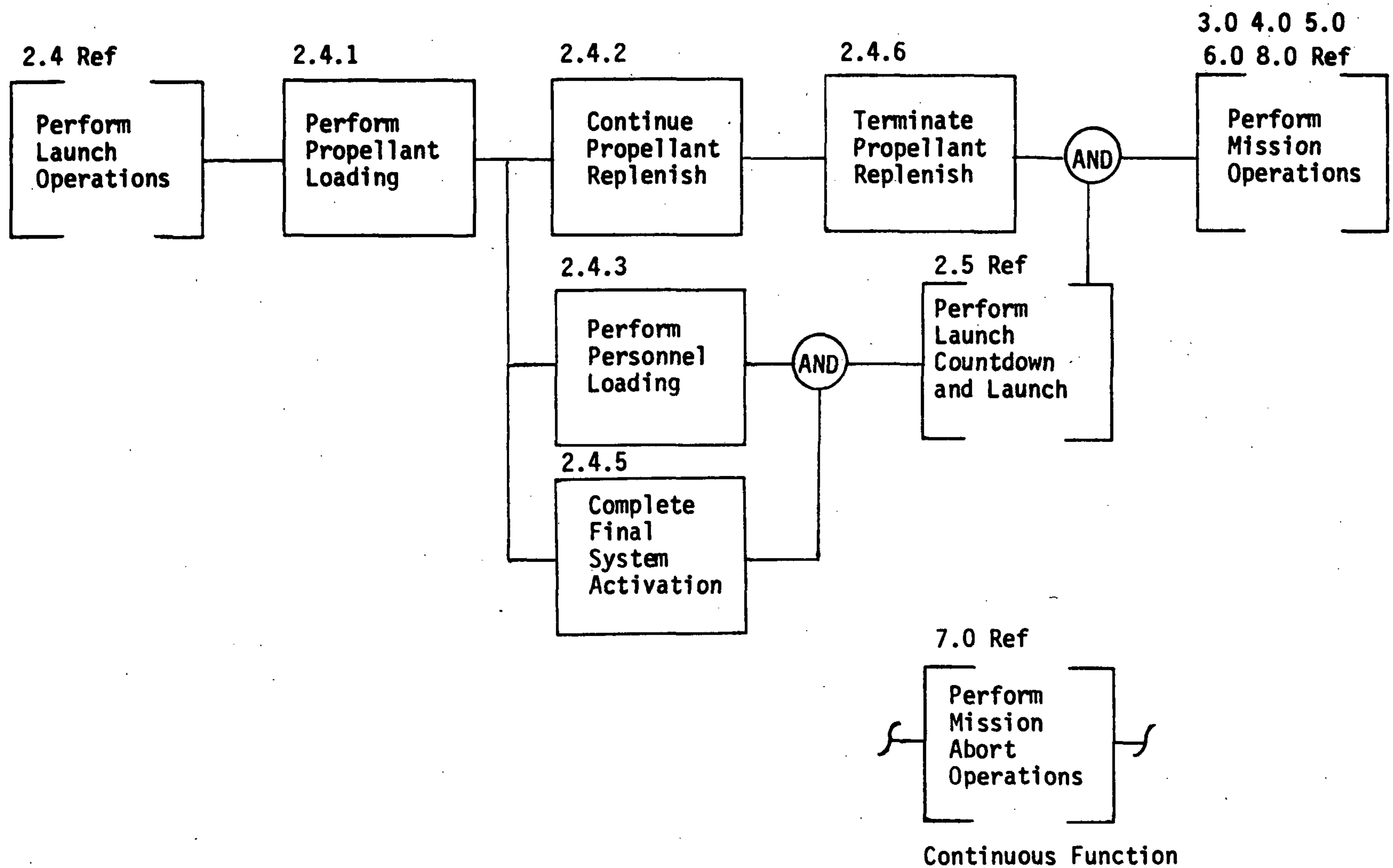


Figure A-3 Perform Launch Operations

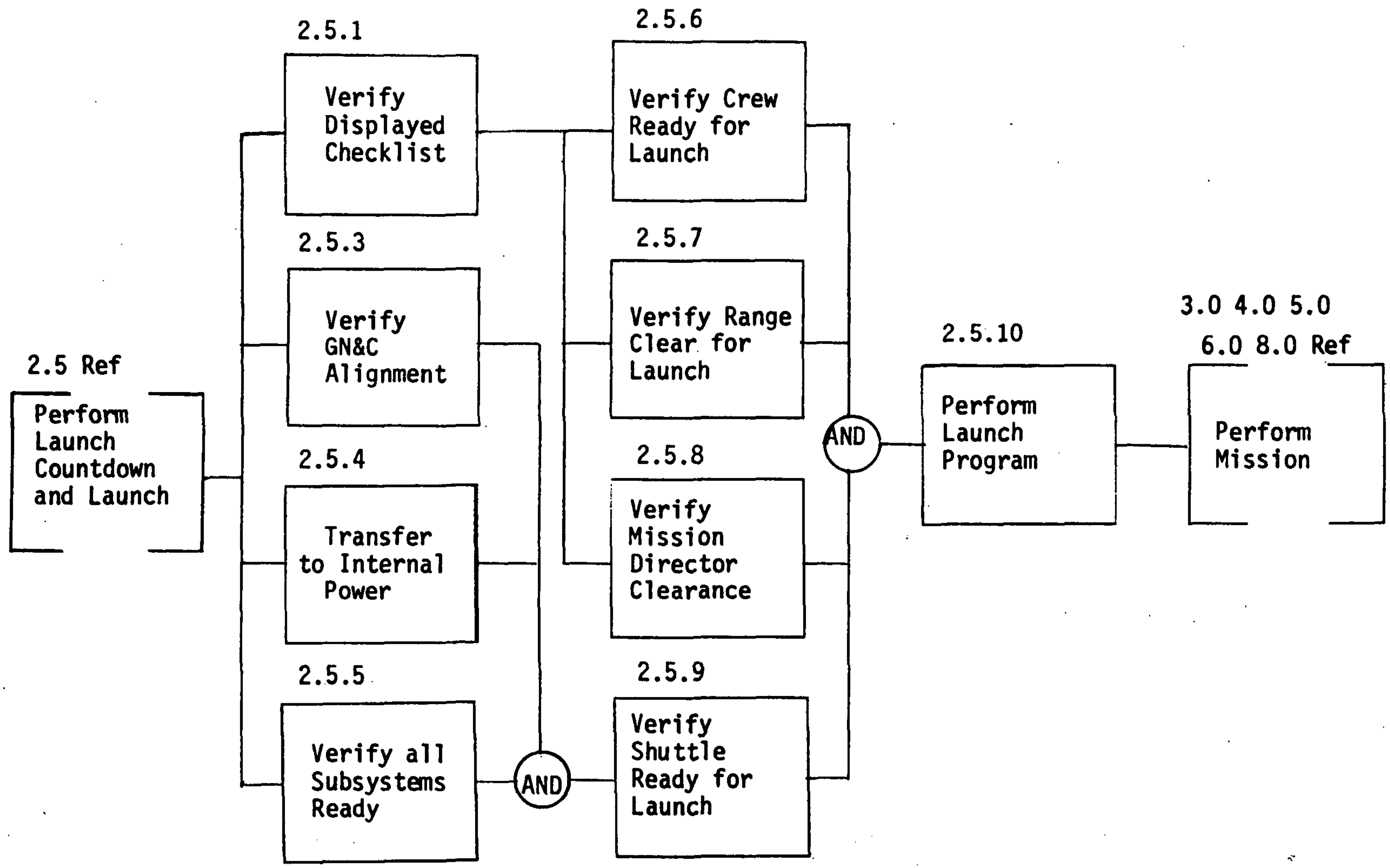
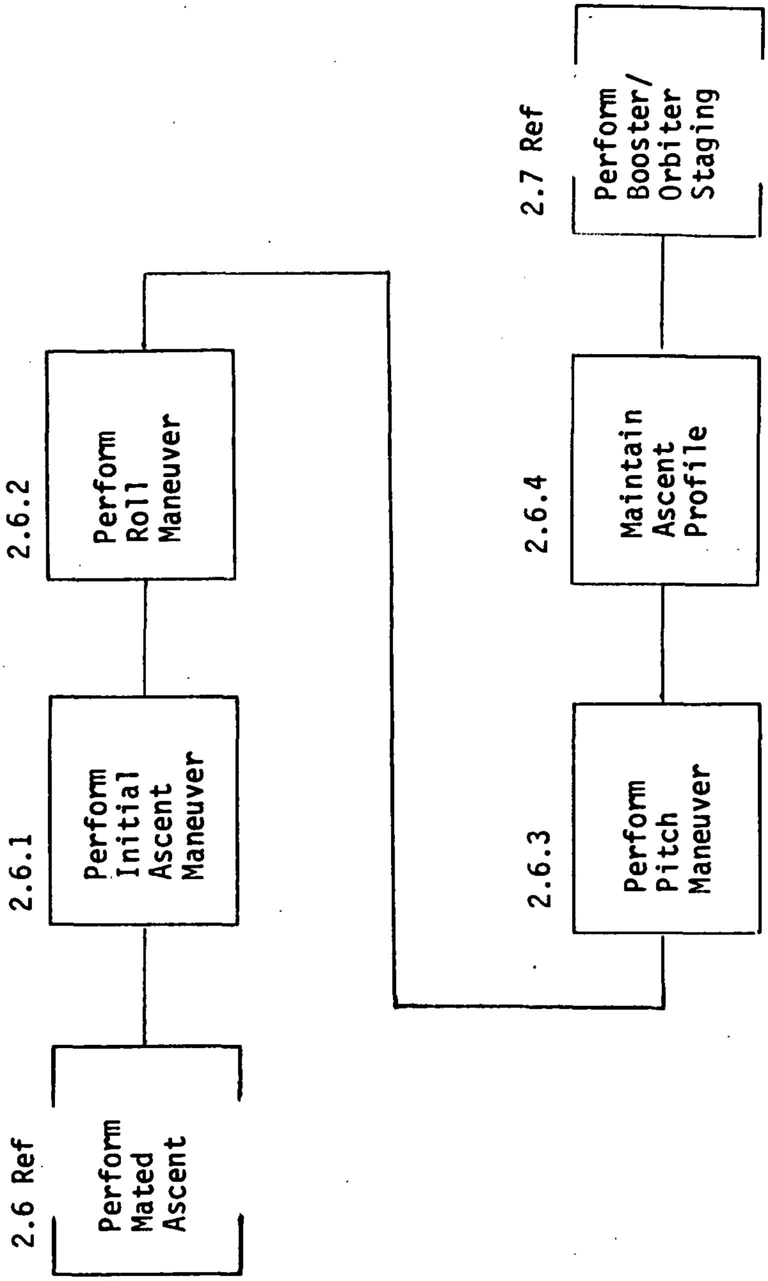


Figure A-4 Perform Launch Countdown



Note: Monitoring of Vehicle Performance is a Continuous Function

Figure A-5 Perform Mated Ascent

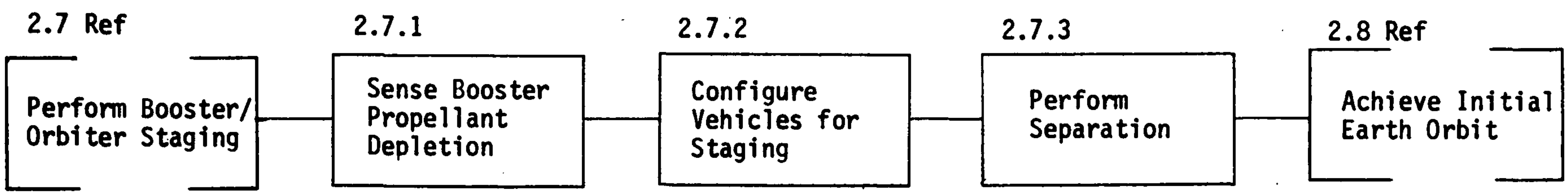


Figure A-6 Perform Booster and Orbiter Staging

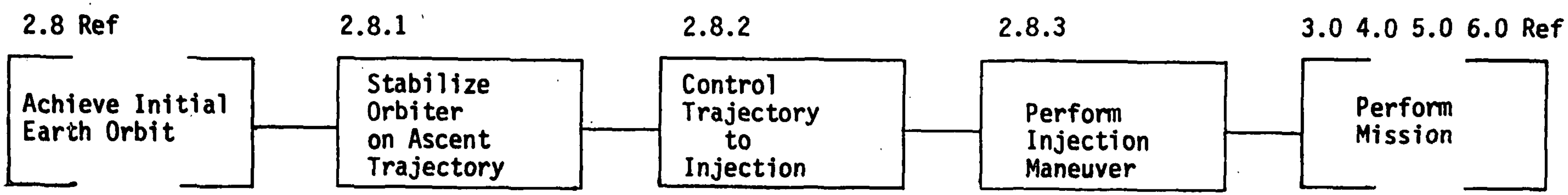


Figure A-7 Achieve Initial Earth Orbit

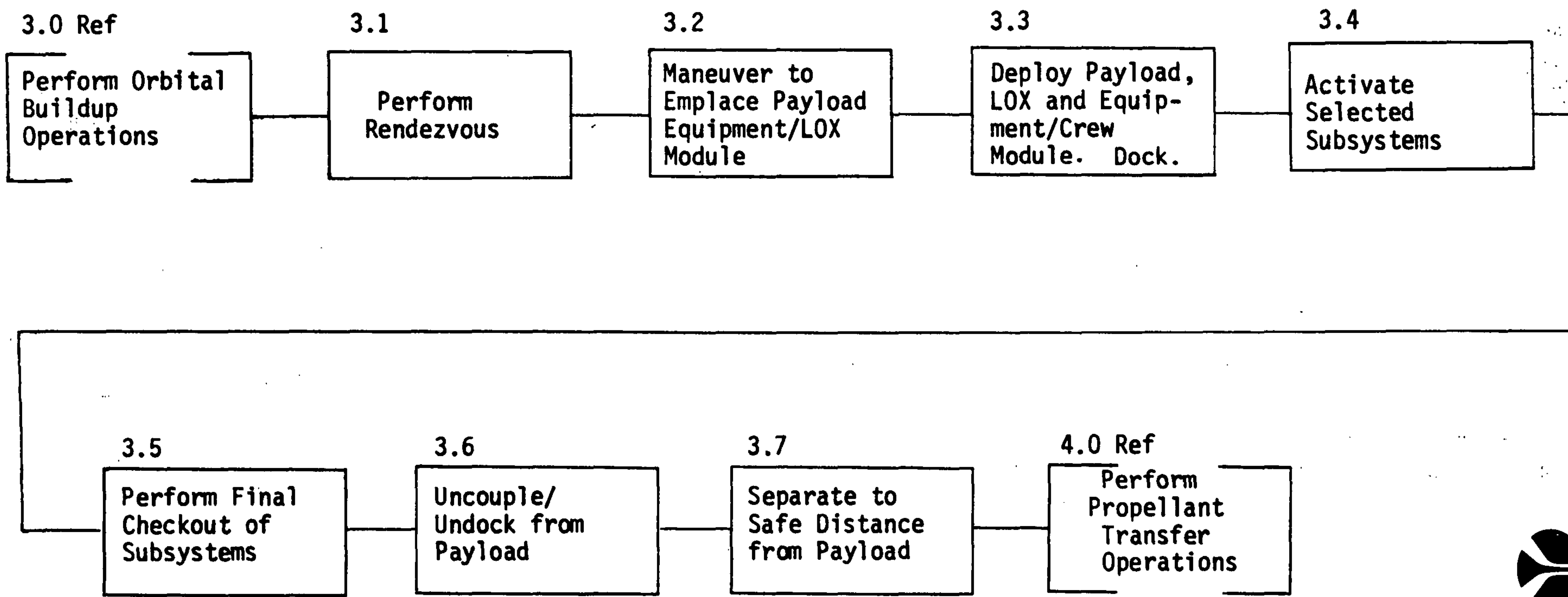


Figure A-8 Perform Orbital Buildup Operations

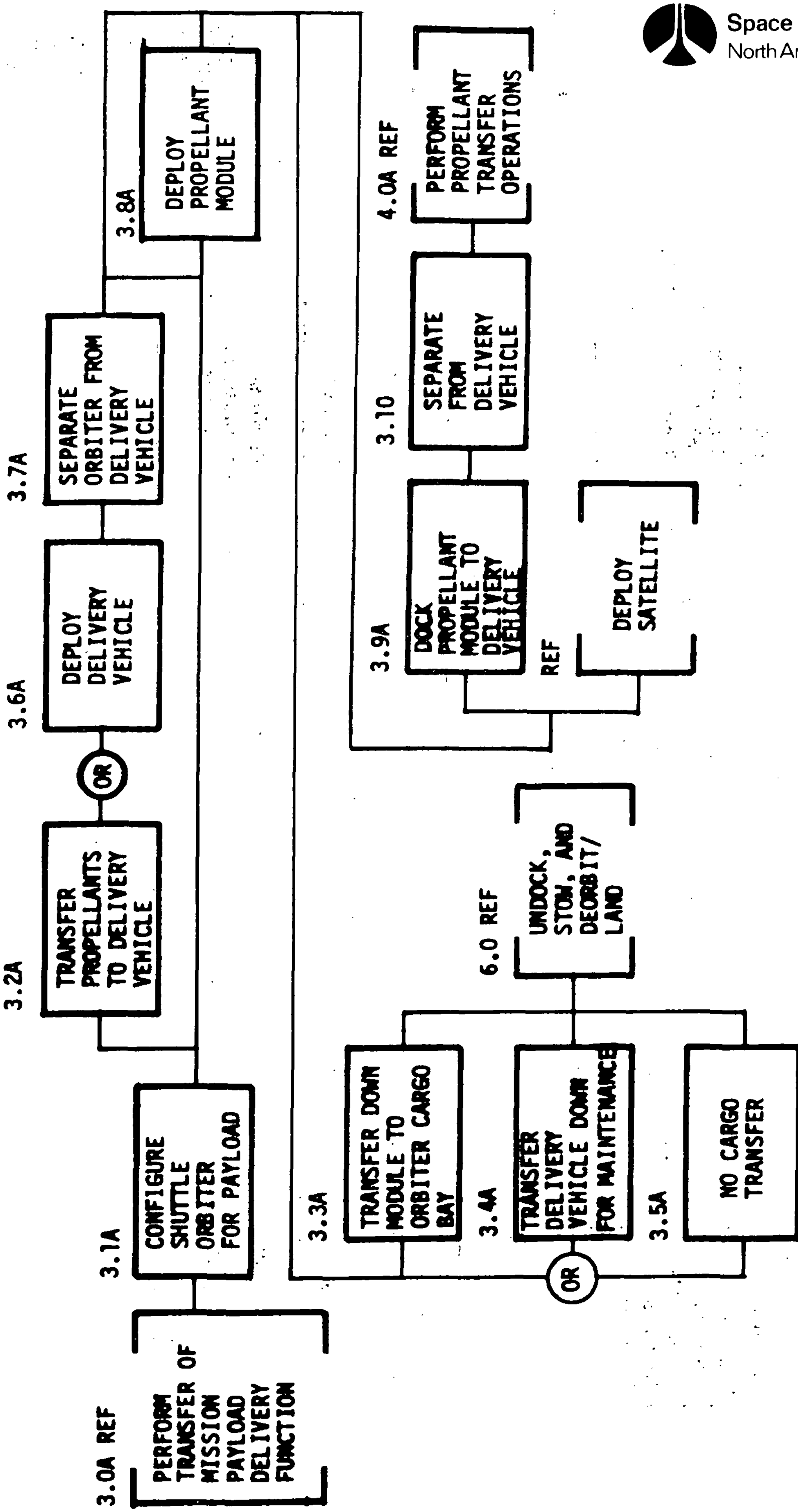


Figure A-9 Perform Transfer of Mission Payload Delivery Function (Tug/Centaur GT/FW-4S/Agena/Centaur)

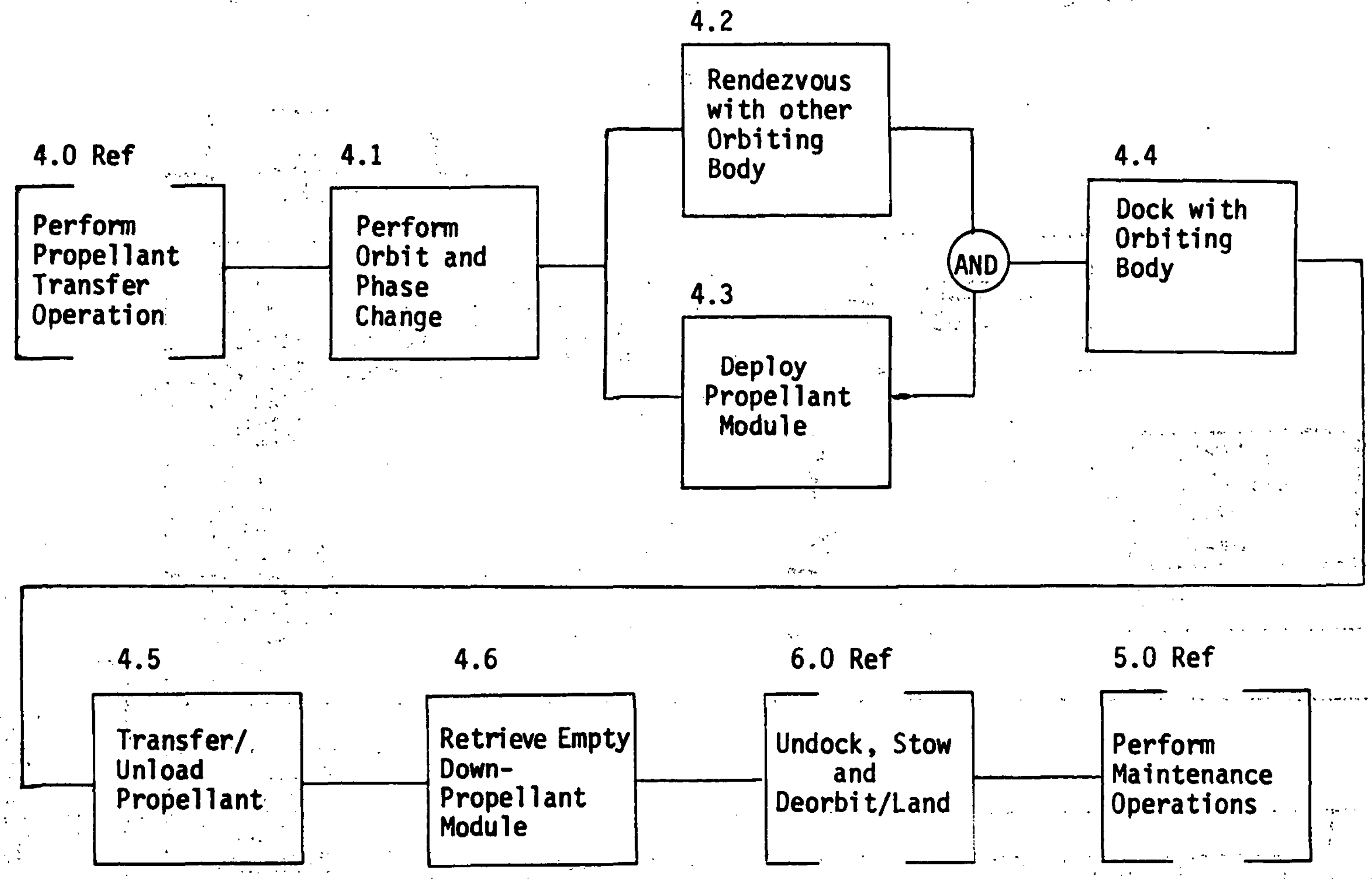


Figure A-10 Perform Propellant Transfer Operations

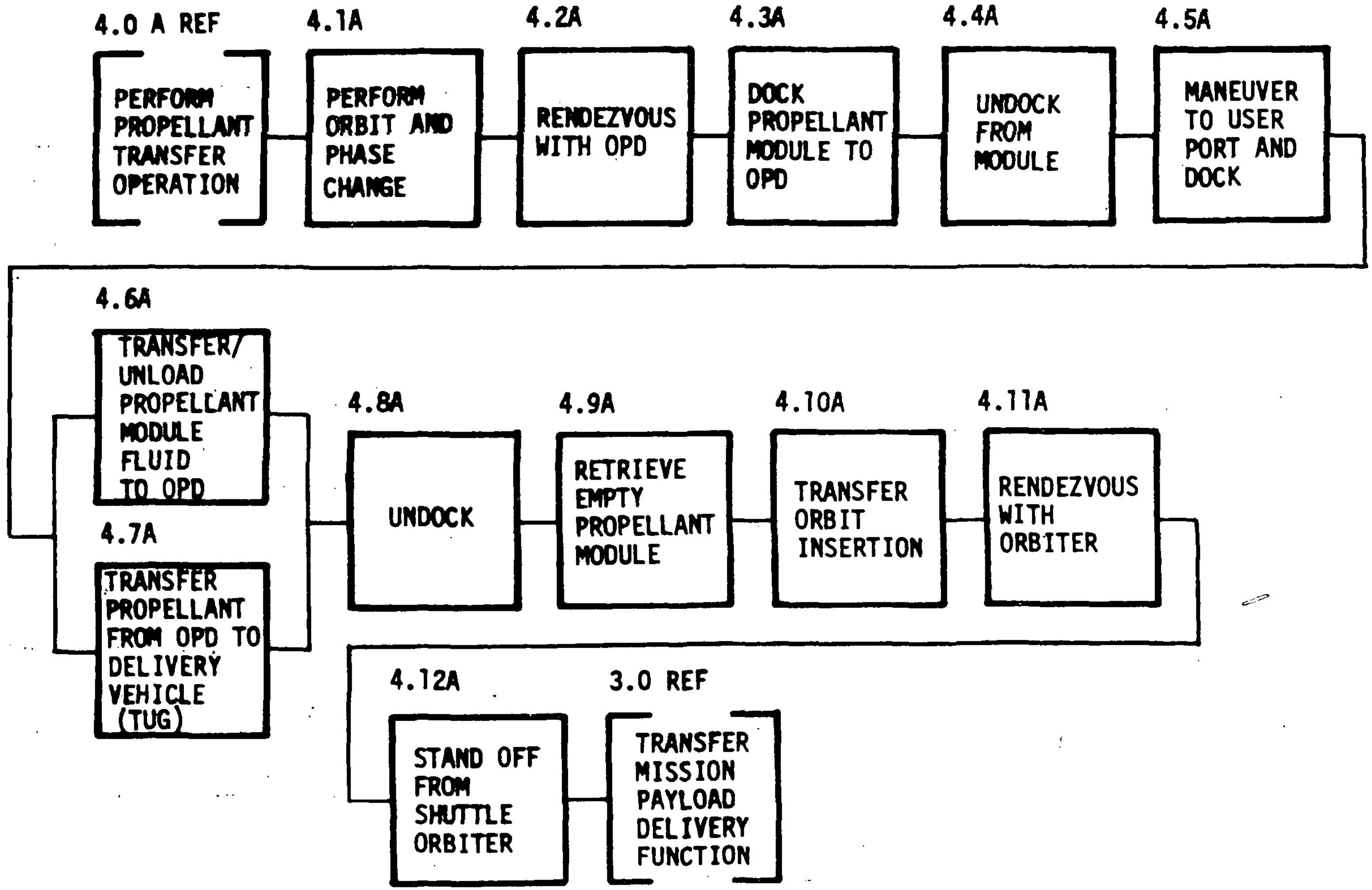


Figure A-11 Perform Propellant Transfer Operation (Space-Based Tug)

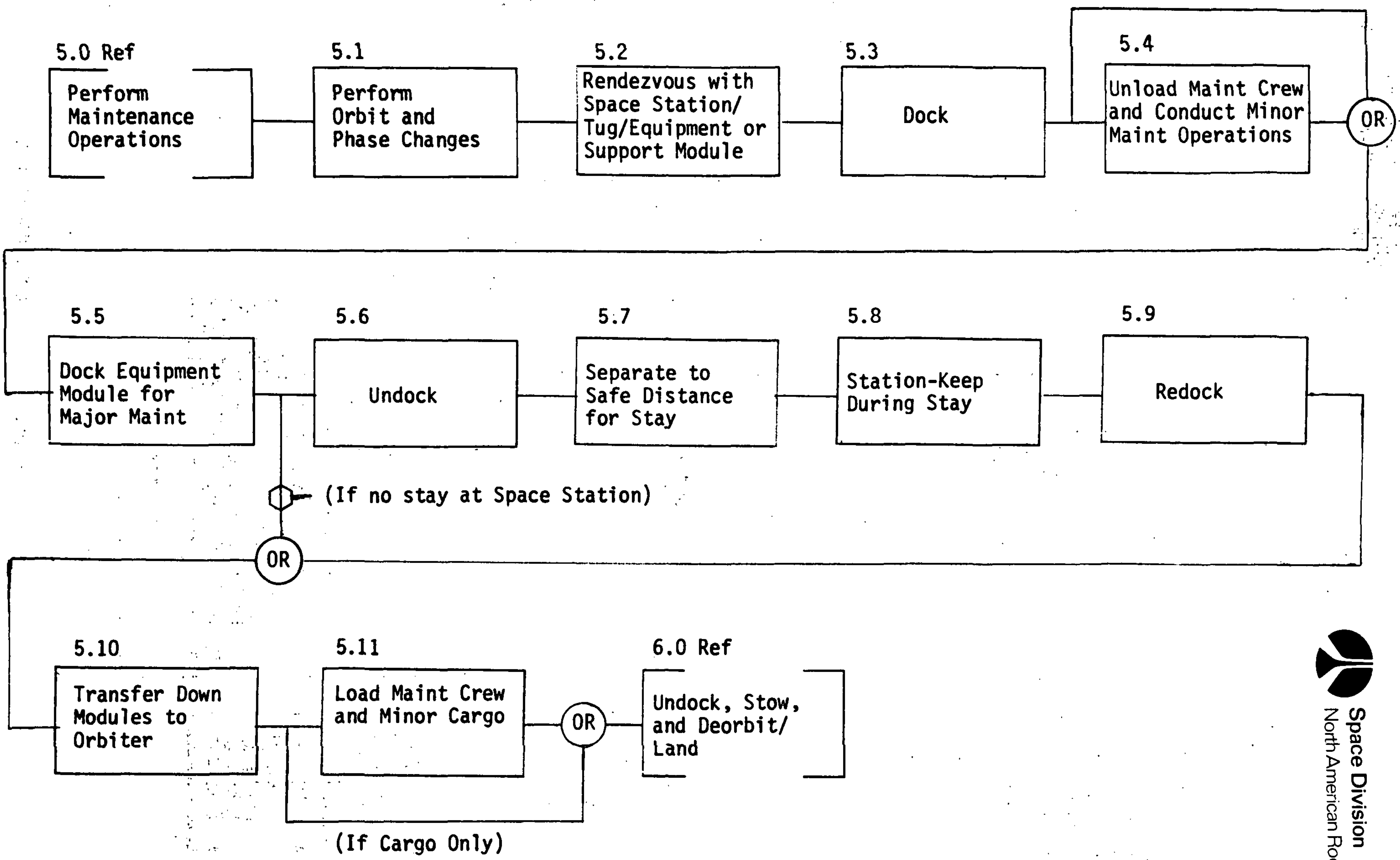


Figure A-12 Perform Maintenance Operations

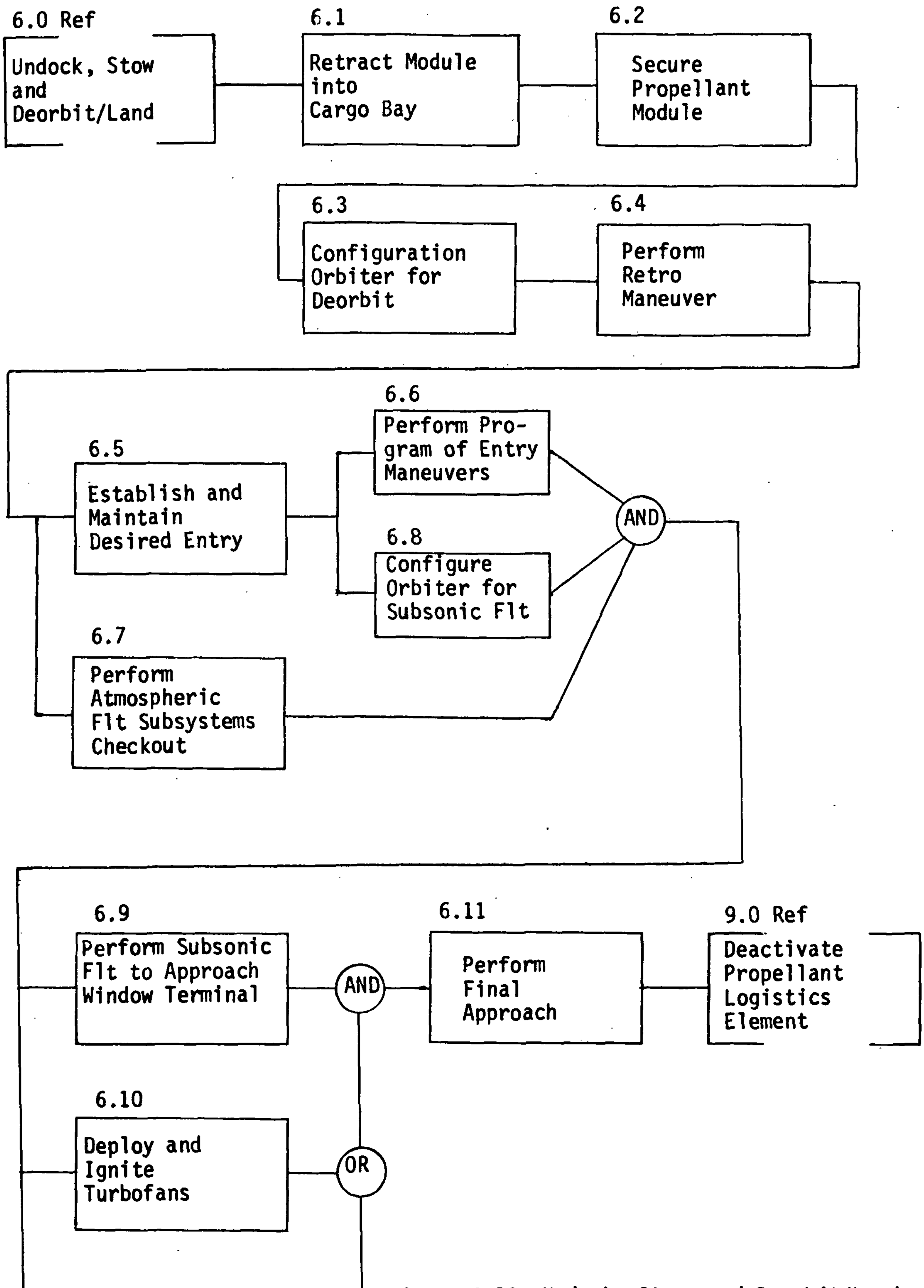


Figure A-13 Undock, Stow, and Deorbit/Land

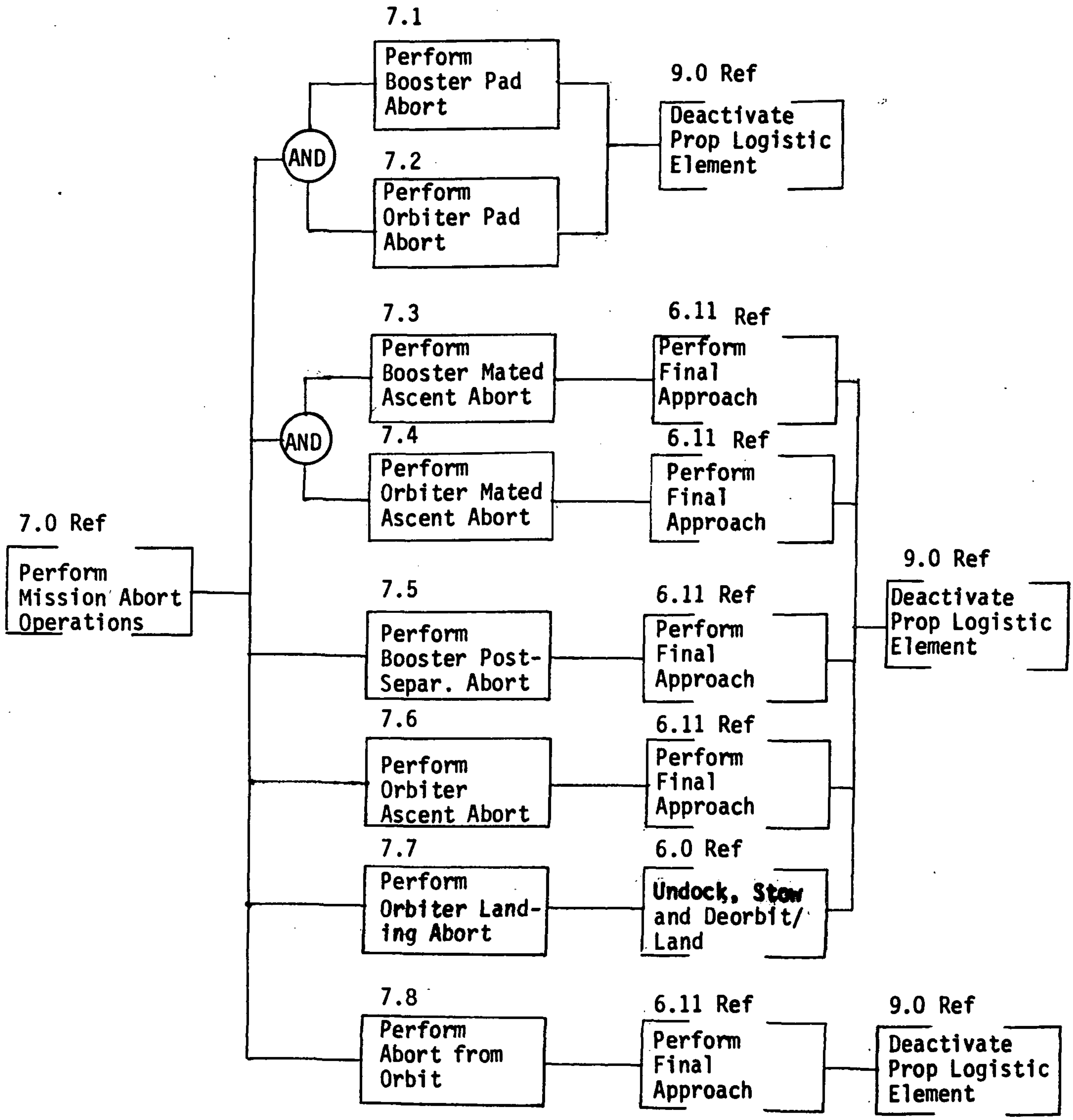


Figure A-14 Perform Mission Abort Operations

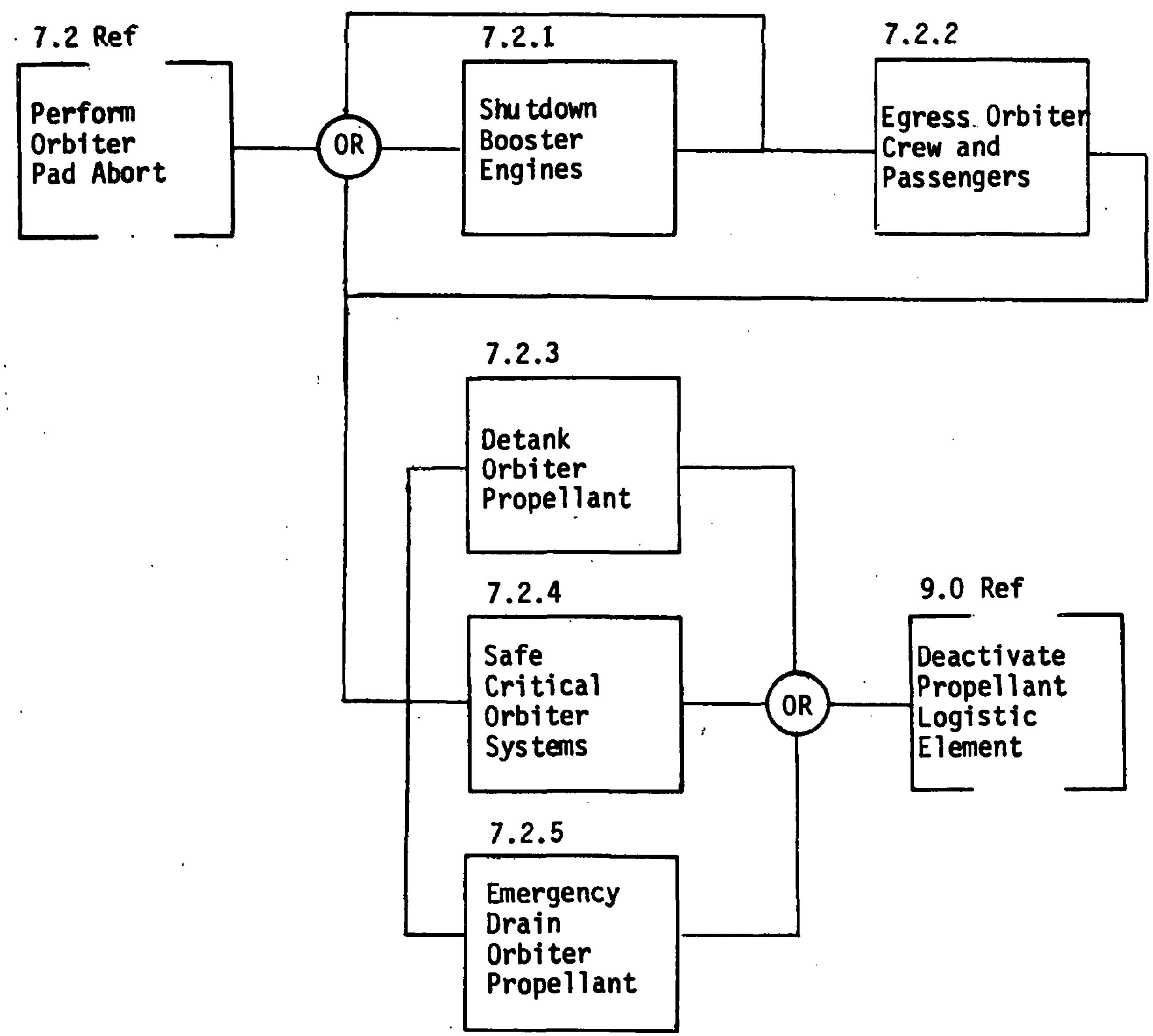


Figure A-15 Perform Orbiter Pad Abort

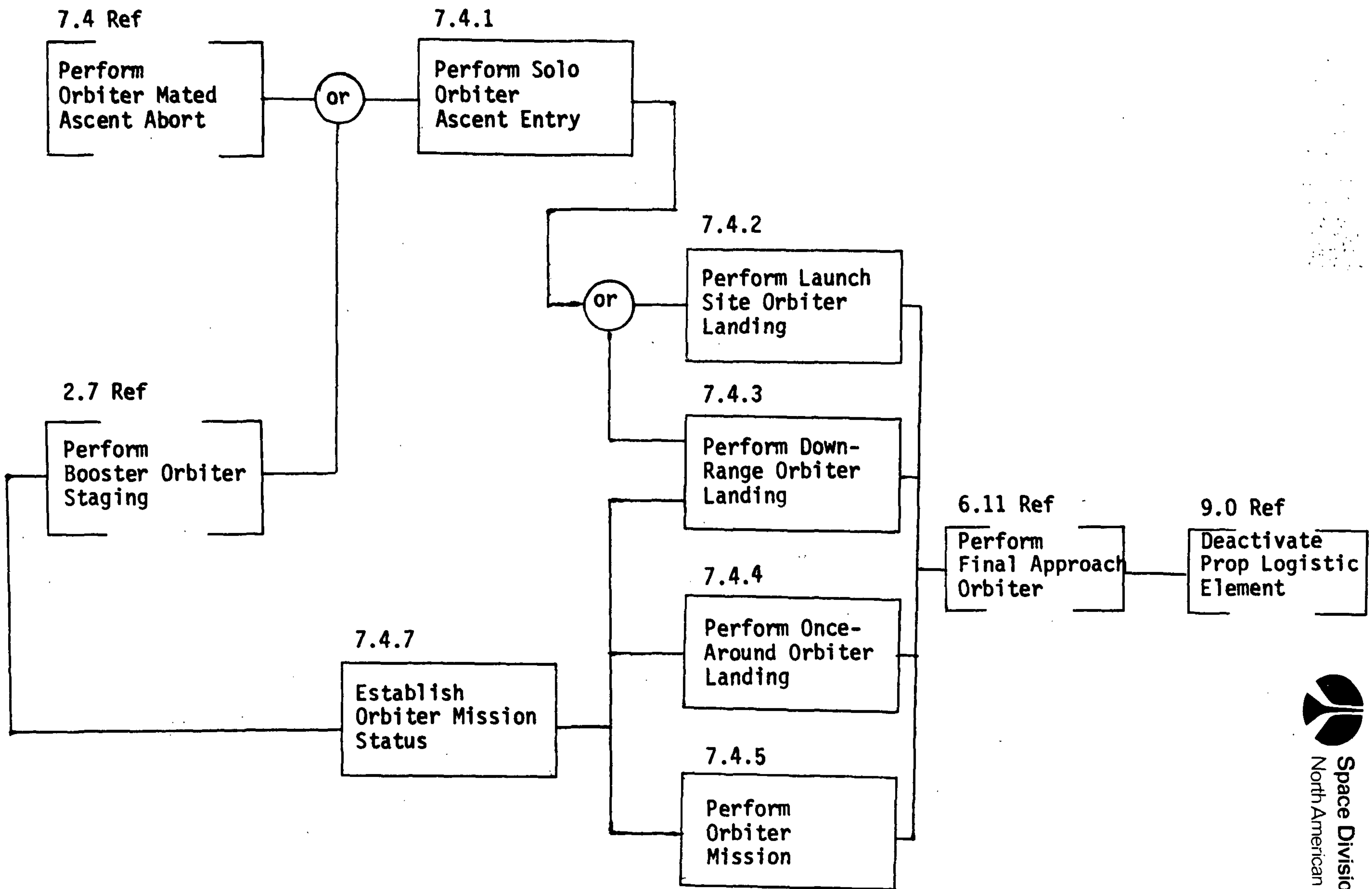


Figure A-16 Perform Orbiter Mated Ascent Abort

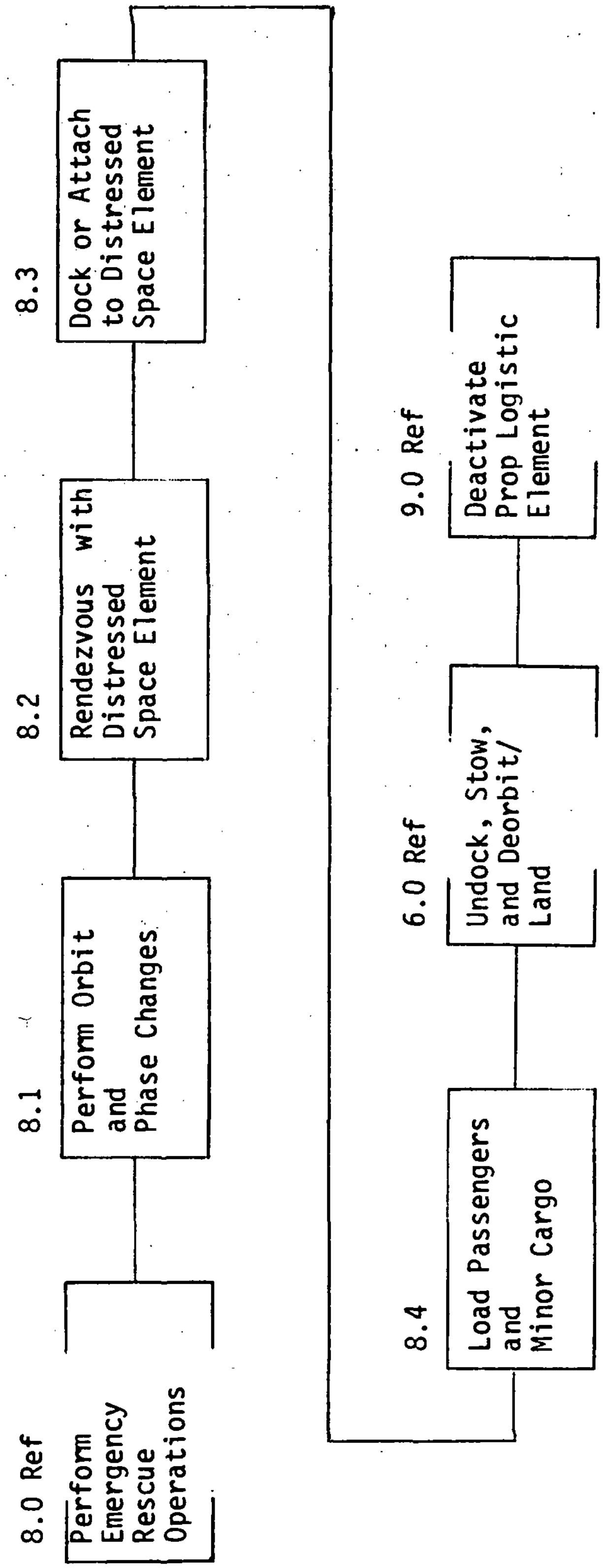


Figure A-17 Perform Rescue Mission

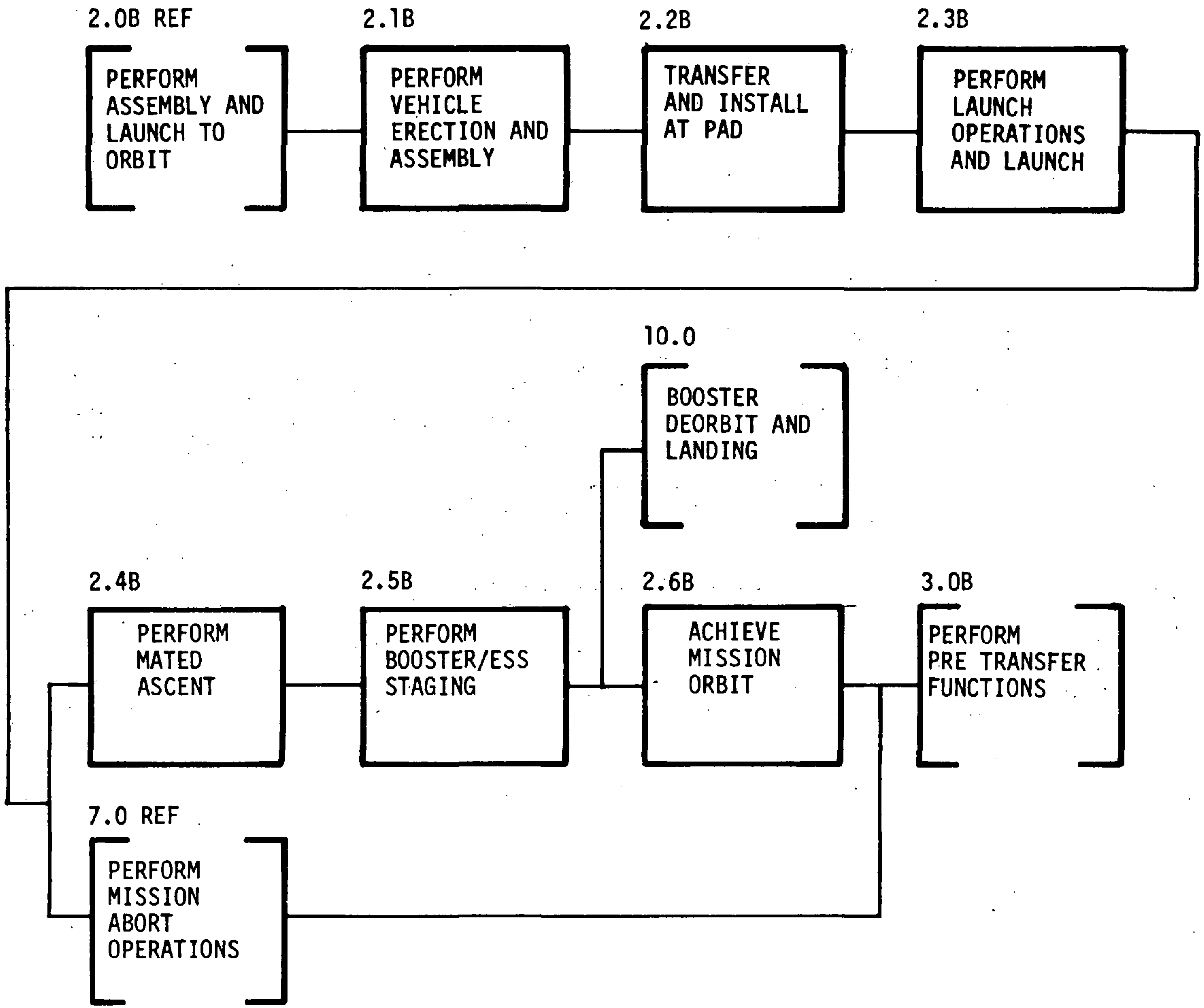


Figure A-18 Perform Assembly and Launch to Orbit
(Shuttle Booster/ESS/Large Propellant Tank)

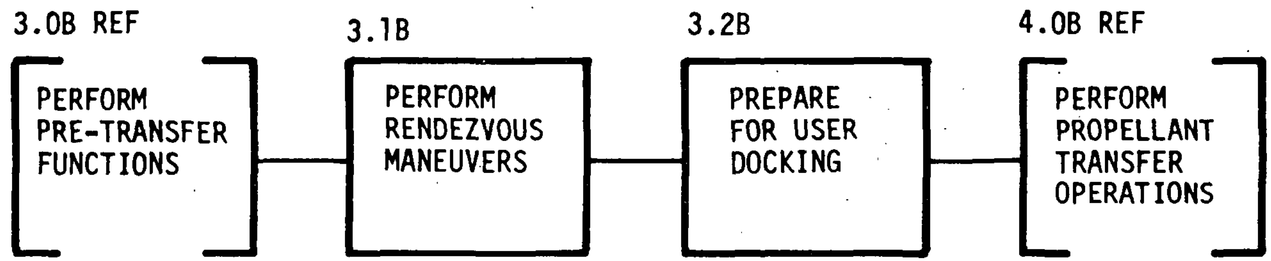


Figure A-19 Perform Pre-Transfer Functions

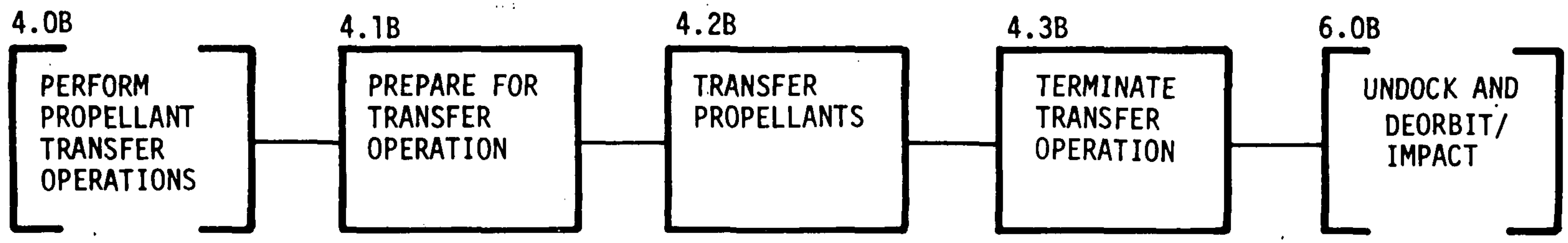


Figure A-20 Perform Propellant Transfer Operations (ESS/Large Propellant Tank to CIS/RNS)

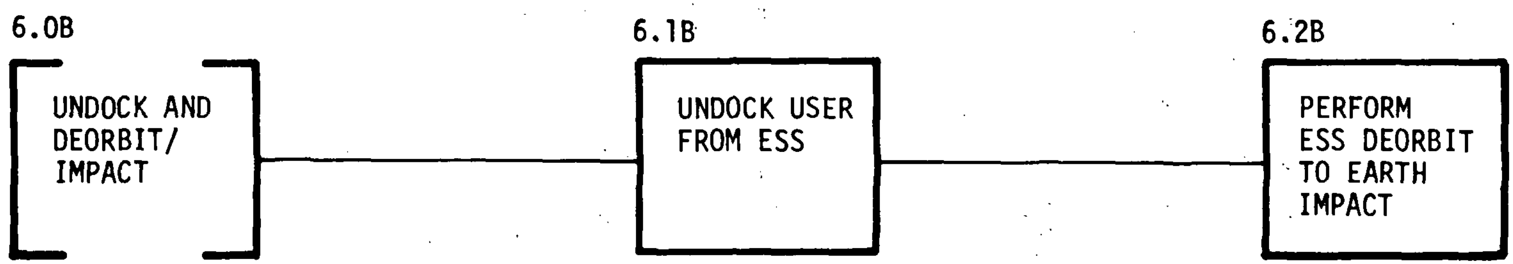


Figure A-21 Undock and Deorbit/Impact (ESS/Large Propellant Tank)

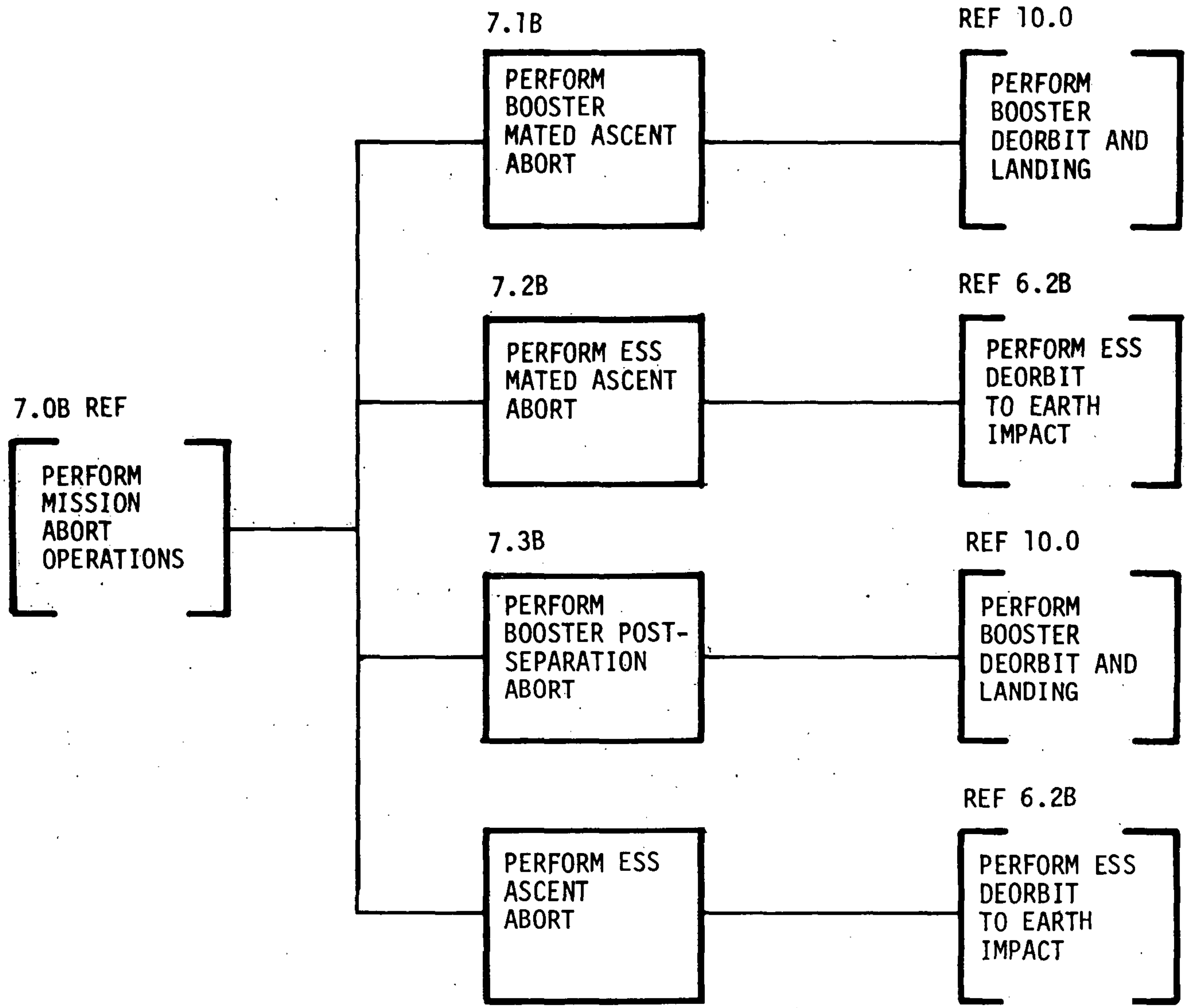


Figure A-22 Perform Mission Abort Operations

APPENDIX B

FAILURE MODE AND EFFECTS ANALYSIS

The representative orbital propellant logistic operations described in the previous section with conceptual element subsystems and interfaces, are analyzed for failure mode effects as they relate directly to System Safety in the propellant logistic operation. In certain cases where unique or otherwise accentuated problems could impact the propellant logistic operations, they are also identified. Conceptual configurations and designs were used from available studies.

1. Correlation of FMEA with Functional Flow Diagrams

   The association between the function and failure for purposes of continuity are structured for the convenience of the reader. The FMEA forms contain a FMEA number in the upper right hand corner. This number is also the number of the functional flow block diagram (FFBD). The Reference FFBD in the first column on the left is the Reference FFBD under which the FFBD is contained. The operational step in the next column is that function occurring in the FFBD number and is associated specifically with the mission phase indicated in the upper left hand corner.

2. Ground Rules and Assumptions

   a. The orbiter vehicle is baselined for this analysis as the -161C Model configuration defined in the NR Phase B Final Report, SD71-114.

   b. The shuttle booster is assumed not to have an interface with the propellant logistic elements in the orbiter cargo bay.

   c. Payload propulsive stages which are stowed in the orbiter cargo bay in a propellant loaded condition are not considered propellant logistic operations, but rather delivery cargo.

   d. The propellant logistic operation is unmanned and fully automated, except for the orbiter element and where orbital maintenance operations or modular replacement of components on the LSF are required.

   e. No single malfunction or credible combination of malfunctions and/or accidents shall result in injury to personnel or loss of mission.

   f. The tug has an ability to add a crew module to its capability in support of LSF maintenance, if required.

g. Orbital propellant logistics operations involve only those operations necessary to supply the user, propellants in earth orbit.

h. For purposes of this representative propellant logistic operation the assumption is made that any of the individual elements of the logistic system are capable of docking with any other element in the system and that docking indexing of these elements will properly align the line interconnect fixture.

i. It is assumed that all elements of the logistic system requiring or providing propellant fluid transfer will be configured with a line interconnect fixture common to all elements.

3. Orbiter Related Subsystems Used in FMEA

The basic configuration and performance of the shuttle orbiter used in this study is shown in Figure B-1. It has been defined in the NR Phase B Final Report, SD71-114.

Payload Handling and Docking

The functions of payload and propellant tank module deployment, payload and propellant tank module retrieval and docking are accomplished through the use of a pair of manipulator arm assemblies. The manipulator arms are located on either side of the personnel-to-payload access tunnel and are stowed along the cargo bay to provide a clear volume for the payload of 15 feet diameter by 60 feet long. A cargo specialist station is located in the personnel access tunnel with visibility provisions for line-of-sight viewing of the manipulator operation. The direct vision is augmented by closed-circuit TV with cameras mounted on the manipulator arms and in the cargo bay to provide visual check of the payload stowage latching and unlatching. Figure B-2 shows the significant features of the PHDS (Payload Handling and Docking System).

The total PHDS comprises two manipulator arms, a docking adaptor, a manipulator operator station, an airlock docking port, a payload retention system and a closed-circuit TV system to augment direct vision capability and provide visibility for close tolerance operation out of direct view from the cargo specialist.

Docking is to be accomplished by the orbiter first matching orbit and station-keeping with the other stabilized body at a distance of no more than 50 feet and not less than 25 feet. The docking is to be accomplished through the use of the payload handling and docking (PHDS) system. The manipulator arms of the PHDS are used to first deploy a docking adaptor (if required) and then to attach this adaptor to the crew or equipment module or target. Just prior to physical acquisition, the stabilization systems of the target must be deactivated. The manipulator arms are then used to draw the two bodies together to a docked configuration.

ORBITER WEIGHTS

INERT WEIGHT	237,700 LB (107,800 KG)
PROPELLANT (MAX CAPACITY)	
ASCENT	562,000 LB (255,000 KG)
OMS	39,000 LB (17,700 KG)

PAYLOAD CAPABILITY

BAY SIZE	15' DIA x 60' (4.57 x 18.3 M)
TO 100 nmi AT 28.5°	65,000 LB (29,500 KG)
TO 100 nmi AT 90°	40,000 LB (18,100 KG)

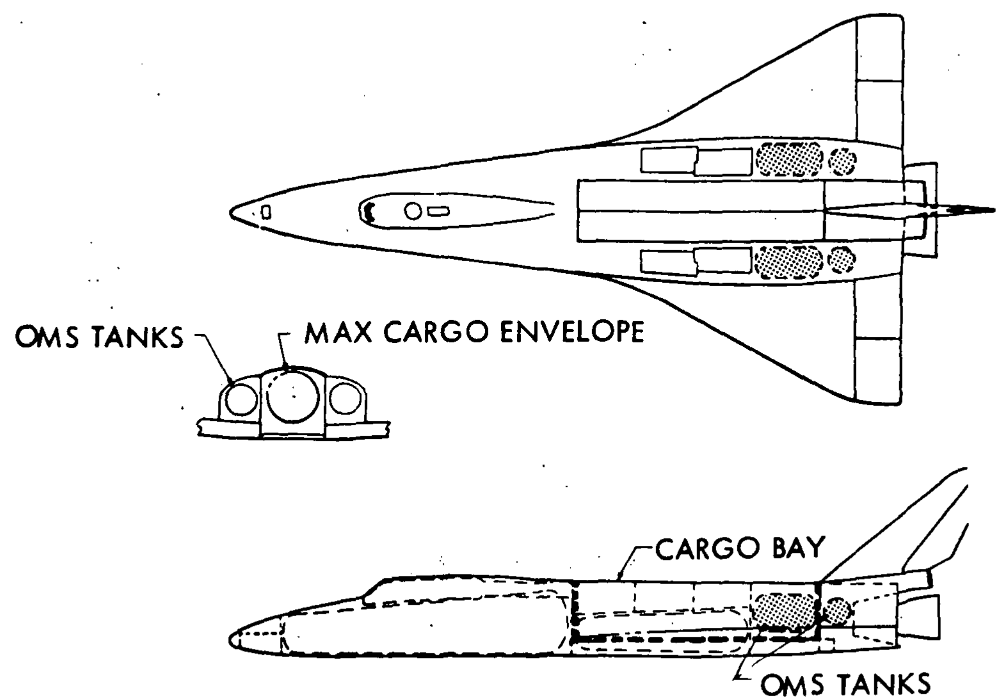


Figure B-1 Shuttle Orbiter

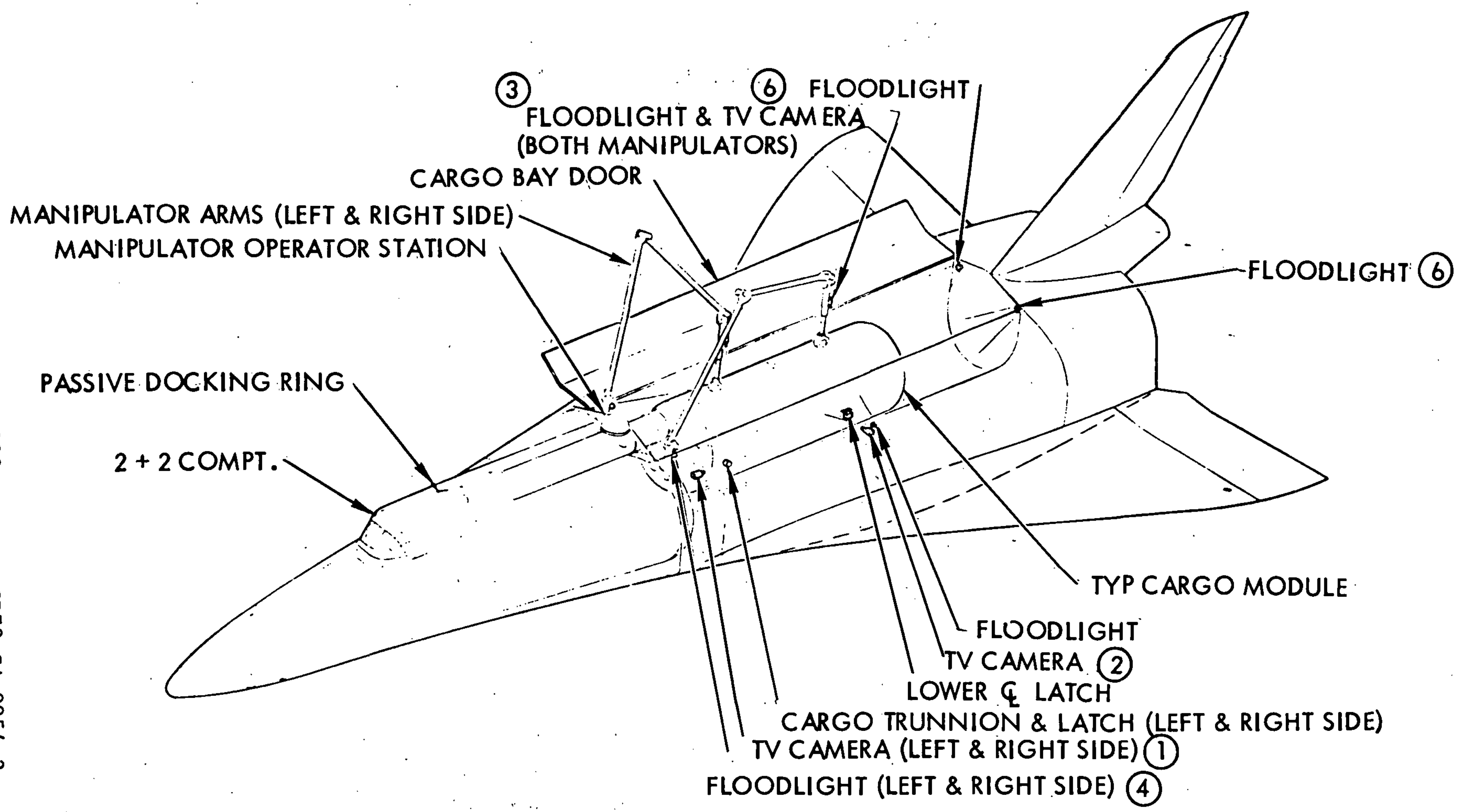


Figure B-2 Payload Handling and Docking System

Down payloads such as the tug, to be retrieved, are so designed that their stabilization capabilities fall within the proper limits. After physical acquisition or engagement of a detached payload by the PHDS, attitude control of the payload ceases.

The PHDS does not intrude into the 15-foot diameter by 60-foot length of the payload volume. The PHDS has the capability of docking the orbiter to any of the passive targets and transferring cargo from the orbiter to any of the remaining ports on the LSF, or from the passive targets to the orbiter cargo bay. Alignment characteristics for docking operations with respect to the orbiter's frame of reference are shown in Figure B-3.

Removal of the docking hardware in whole or in part is not required in order to facilitate transfer through the docking port. The docking port is located on the top centerline of the orbiter aft of the crew and passenger compartment and is externally accessible at all times.

The PHDS does not preclude payload cg control and it randomly deploys and/or retrieves payloads. It may be released from the orbiter in zero-g if necessary to allow the closure of the cargo bay doors for safety, during re-entry.

Payload retention in the cargo bay is a function of the PHDS. Payloads can be attached in the cargo bay or at the airlock docking port. Structural attachment loads between the payload and the cargo bay are statically determinant.

<u>Manipulator Arms</u> - Two manipulator arms are used to: provide stability in the removal, deployment, and retrieval of payloads that may vary in mass distribution; provide additional stiffness to one arm by using the second arm to grasp and support the working arm; provide TV viewing from a side angle or varying positions to enhance operational cues for the operator; and provide operational redundancy for the PDRS. One of the arms is shown in Figure B-4.

Each arm has six degrees of rotational freedom, plus at least one degree of freedom for the tool located at the end of the arm. A linear extension of the wrist is considered desirable (to provide short linear travel without requiring movement of the arms) for operations such as initial removal from the stowage latches or engagement of latching or docking devices. A TV camera is mounted near the wrist to provide a view of the hand for close-tolerance operations. A floodlight is included in this installation to provide the necessary illumination. This TV camera/floodlight combination can also be used for side viewing of the other manipulator for other operations.

The manipulator operation is designed basically as a manually operated system with final stowage or initial deployment operations designed as programmed events.

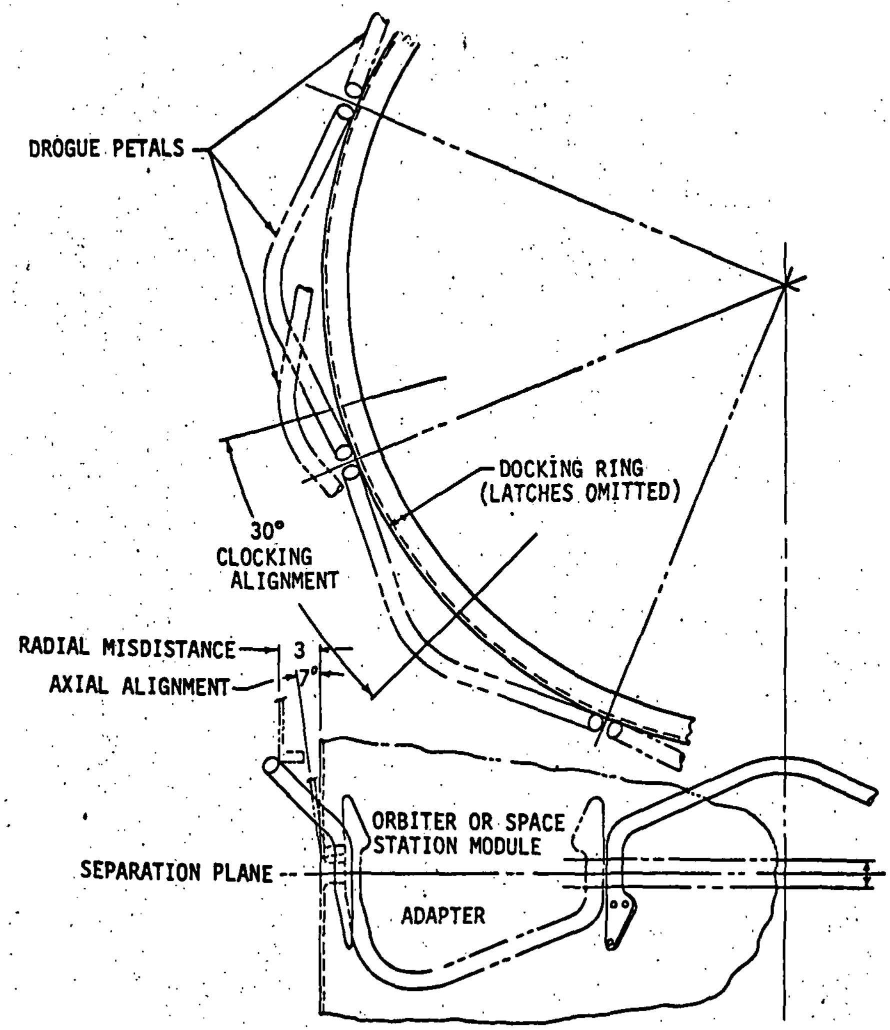


Figure B-3 Docking Concept Alignment Characteristics

Docking Adaptor - The docking adaptor is used in conjunction with the manipulators to execute the docking maneuver between vehicles requiring a transfer of personnel and/or where the vehicle configurations require a separation distance for geometrical clearances. The method of employing the docking adaptor is shown in Figure B-4. A representative detail of the adaptor is shown in Figure B-5.

For orbiter-to-equipment module docking, the adaptor is stowed in the cargo bay of the active orbiter. In these applications, the adaptor is removed from its stowage area by means of the manipulator. It is then positioned on the equipment module to be docked with and latched into place. With the manipulator still attached to the adaptor, the module and vehicle are brought together by the manipulator with the final docking and latching occurring at the active orbiter. With the adaptor latched to both module and vehicle the airlock hatches may be opened for personnel transfer.

The adaptor is essentially an open-ended cylinder with automatic hard docking latches mounted on each end. Operation of these latches may be initiated for release from either end. This release cycle cocks the latches for the next docking operation. Each set of end latches may be selectively operated. The fact that each end of the docking adaptor provides the active male interface enables all other interfaces to be a passive female type, thus providing the advantages of an androgenous system without the usual complexities. In addition, the separate adaptor permits ground maintenance of the unit.

Cargo Specialist Station - The cargo specialist station is located forward of the cargo bay within the personnel-to-payload transfer tunnel. It is designed to provide a hemispherical field of vision for the cargo specialist for the complete operation of payload deployment and retrieval and for vehicle-to-vehicle docking. The payload attach fittings are designed to permit angular and dimensional misalignments within the constraints of the payload clearance envelope. The latches are self-aligning and are provided with remotely-controlled latching mechanisms. Lock and unlock indicators are provided in the cargo specialist station. Normal maintenance of the latch and locking mechanism is accomplished with the payload removed. All fittings are completely accessible from inside the cargo bay.

A personnel transfer port is provided in the cargo bay forward bulkhead to provide personnel access to either a manned crew module (when stowed) or the cargo bay. The cargo bay is not pressurized and has limited insulation for temperature control; therefore, personnel access to the cargo bay during orbit requires EVA. The personnel transfer port is on an extendable section to provide the necessary payload clearance for deployment and retrieval. The port is extended to engage the payload mating ring after stowage of the payload. The reverse procedure is required before payload deployment.

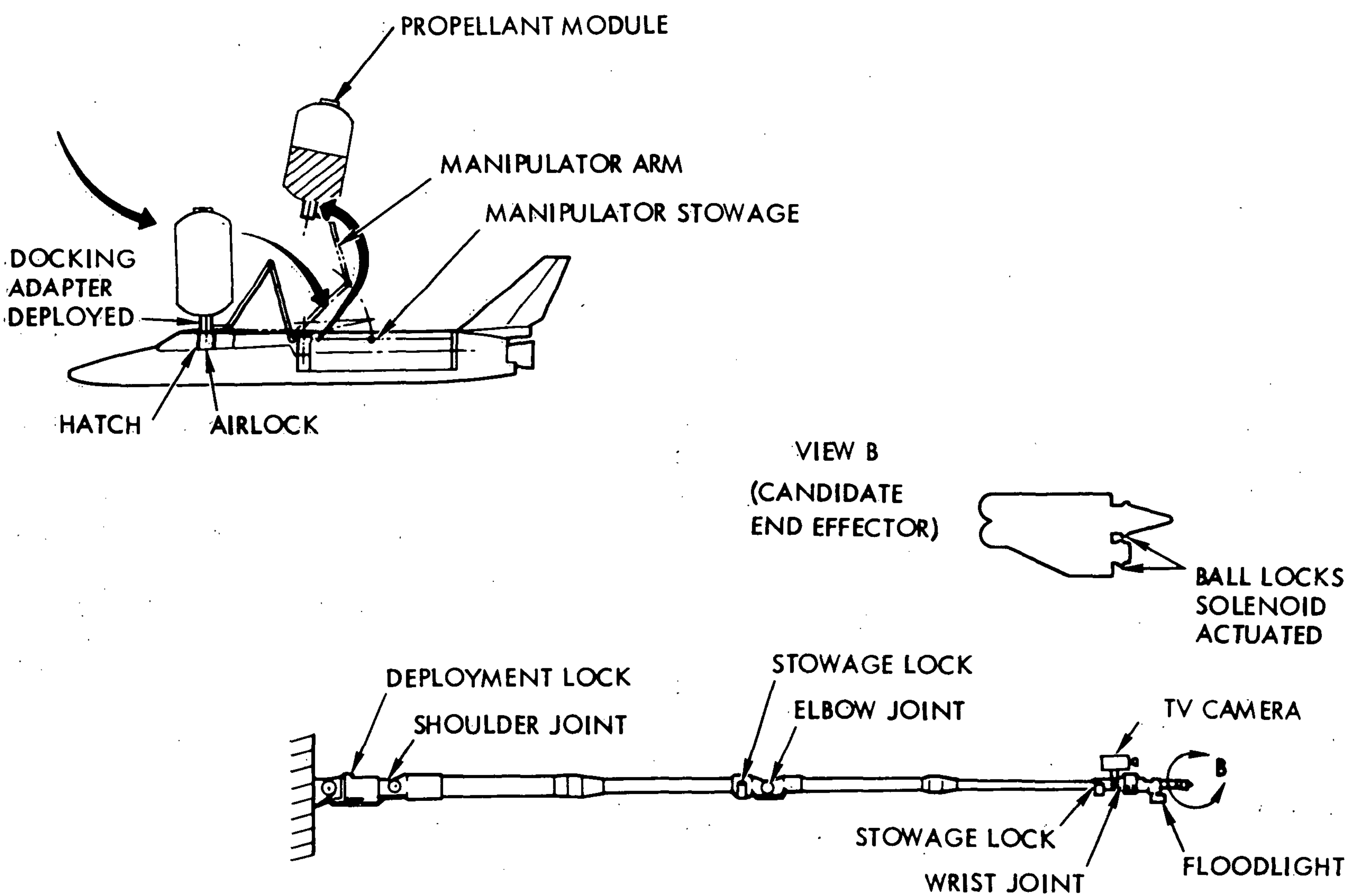


Figure B-4 Standardize Shuttle & Prop Module Configuration

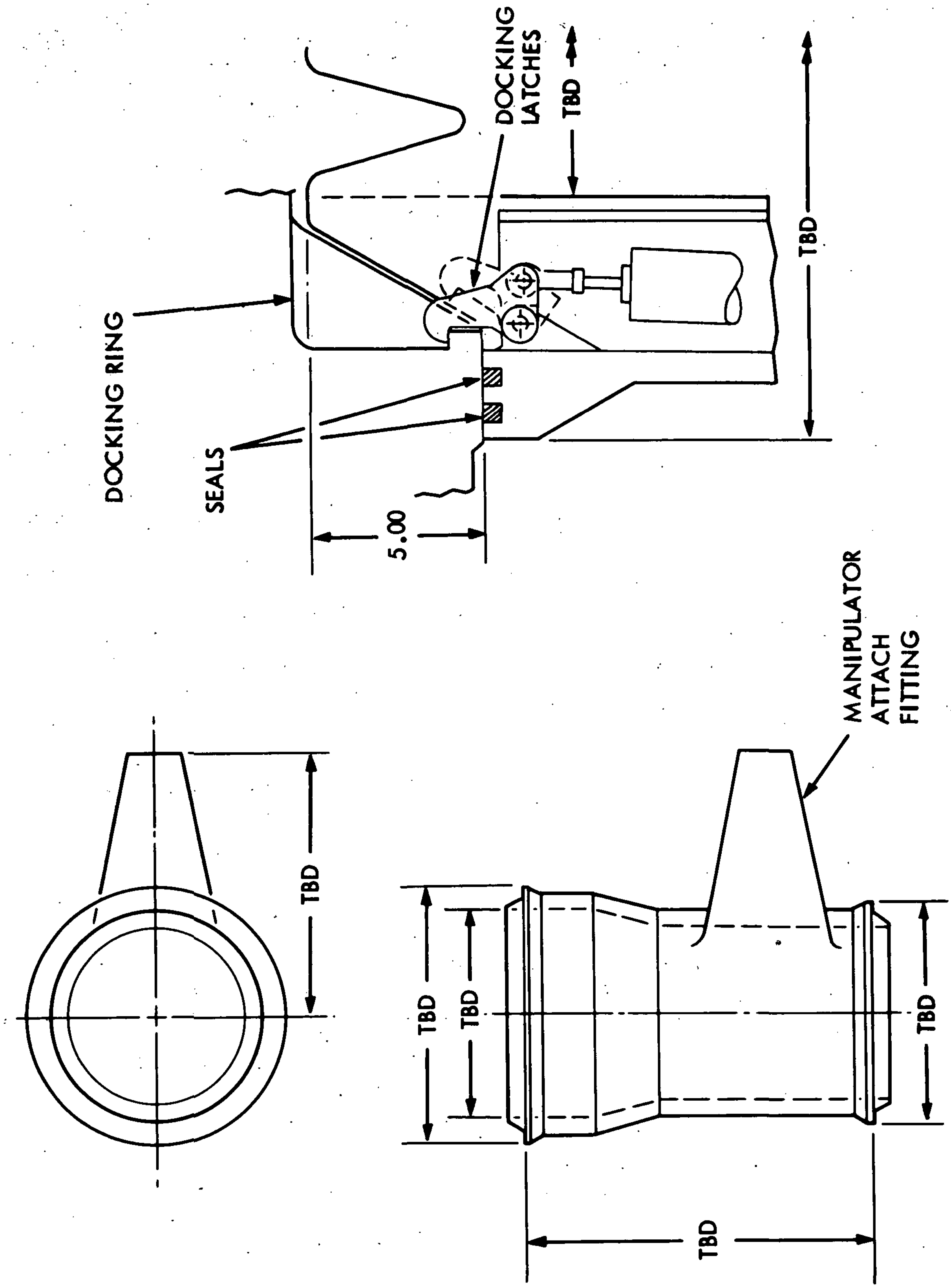


Figure B-5 Docking Adapter

The operator's station is equipped with manipulator controls and the closed-circuit TV displays. A swing-away seat is used to provide personnel clearance when access to the payload bay is required. Figure B-6 shows the general arrangement and location of the cargo specialist station.

The spherical dome protrudes beyond the basic body lines to provide a full hemisphere of visibility. A fairing door is designed to cover the dome and provide environmental protection during launch and re-entry phases.

Closed-circuit TV is used in conjunction with direct visibility and a TV display is located at the operator's station. The viewing of the various TV displays is achieved by switching to the selected camera system for display on the single unit.

Payload Retention - The payload retention system is designed to accommodate payloads 15 feet in diameter by a length up to 60 feet. The forward attach fittings, as illustrated in Figure B-7 are designed to take the axial, vertical, and side loads that may be imposed on the orbiter and payload. The side load is taken on one side only so that unpredicted orbiter or payload deflections are not introduced into the attach fitting. The aft end of the payload is supported by a single fitting on the orbiter centerline. The aft fitting accepts vertical loads only and is designed to accommodate thermal or structural deflections in the lateral direction.

4. LSF Systems Used in FMEA

The LSF configuration and transfer concept baselined in the OPSS feasibility study, NAS7-200, Change Order 1980, are presented in schematic form in Figure B-8.

a. LSF System Description

The LSF for RNS and tug fueling is based on rotational acceleration for fluid flow propellant transfer and uses tankage and structure components derived from S-II. The basic LSF is made up of three separately launched modules that have been joined in orbit. The largest module consists of two LH_2 tanks symmetrically located about a central skirt that contains docking ports and provisions for joining of the other modules. The two smaller modules are sized to be carried within the shuttle orbiter cargo bay. One is principally for LOX storage and it has full propellant transfer capability at its outboard docking port. The other contains most of the subsystems equipment, has a crew interface compartment and has the primary propellants transfer docking port at its outboard end. Additional modules to be considered a part of the LSF system are a crew and maintenance support module and the propellant supply tank.

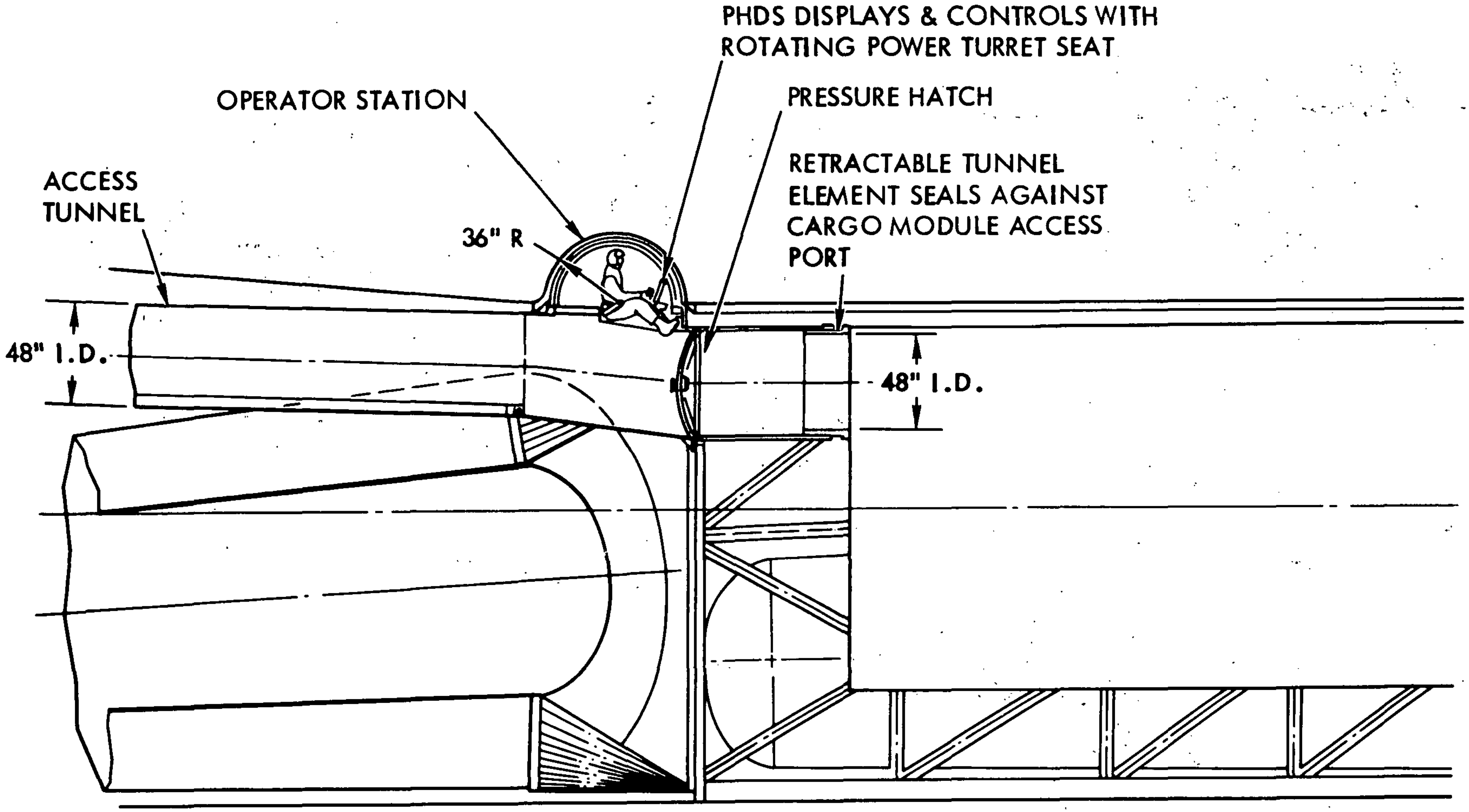


Figure B-6 Cargo Specialist Station

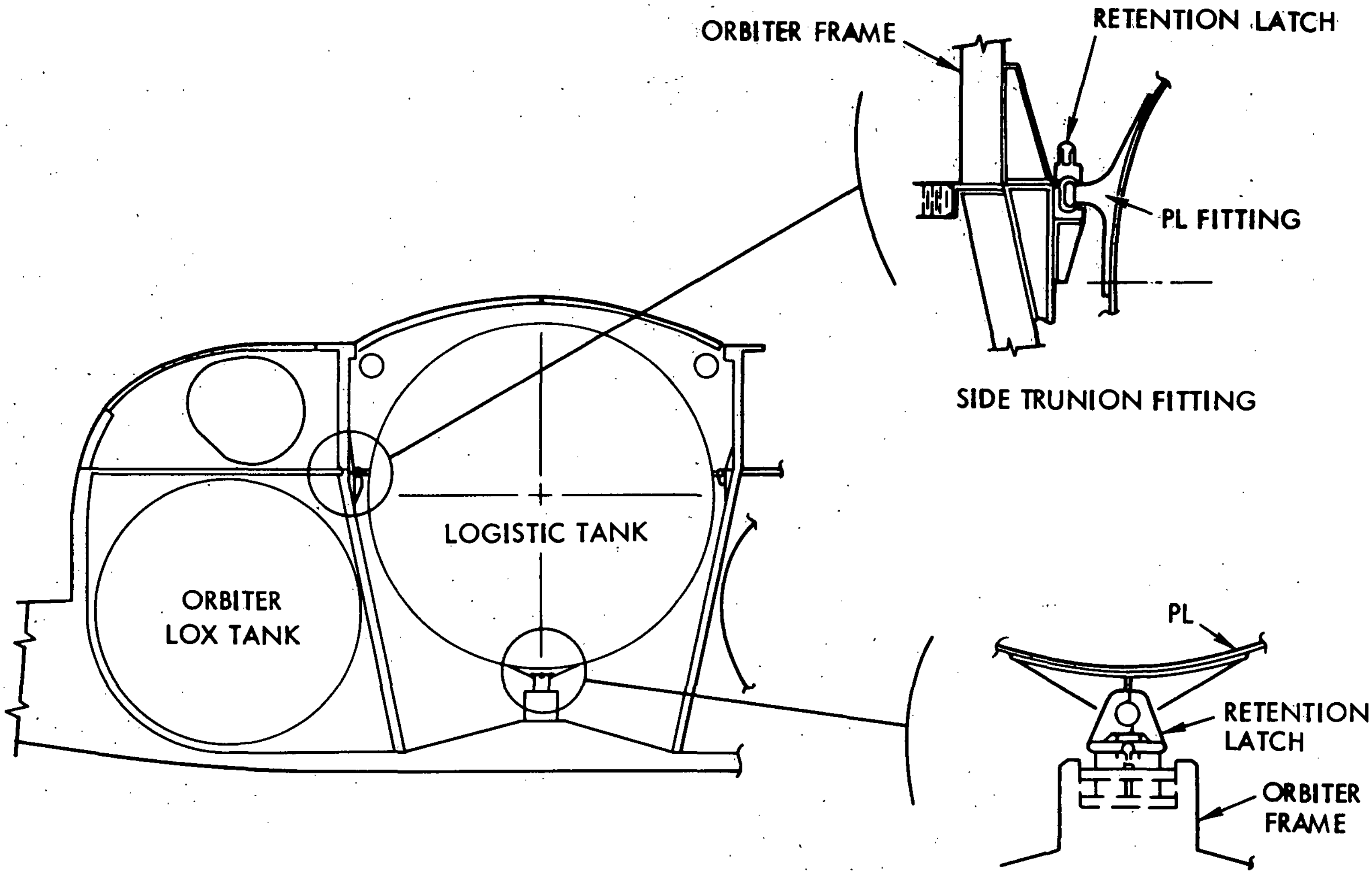


Figure B-7 Logistic Tank & Shuttle Cargo Bay Interface

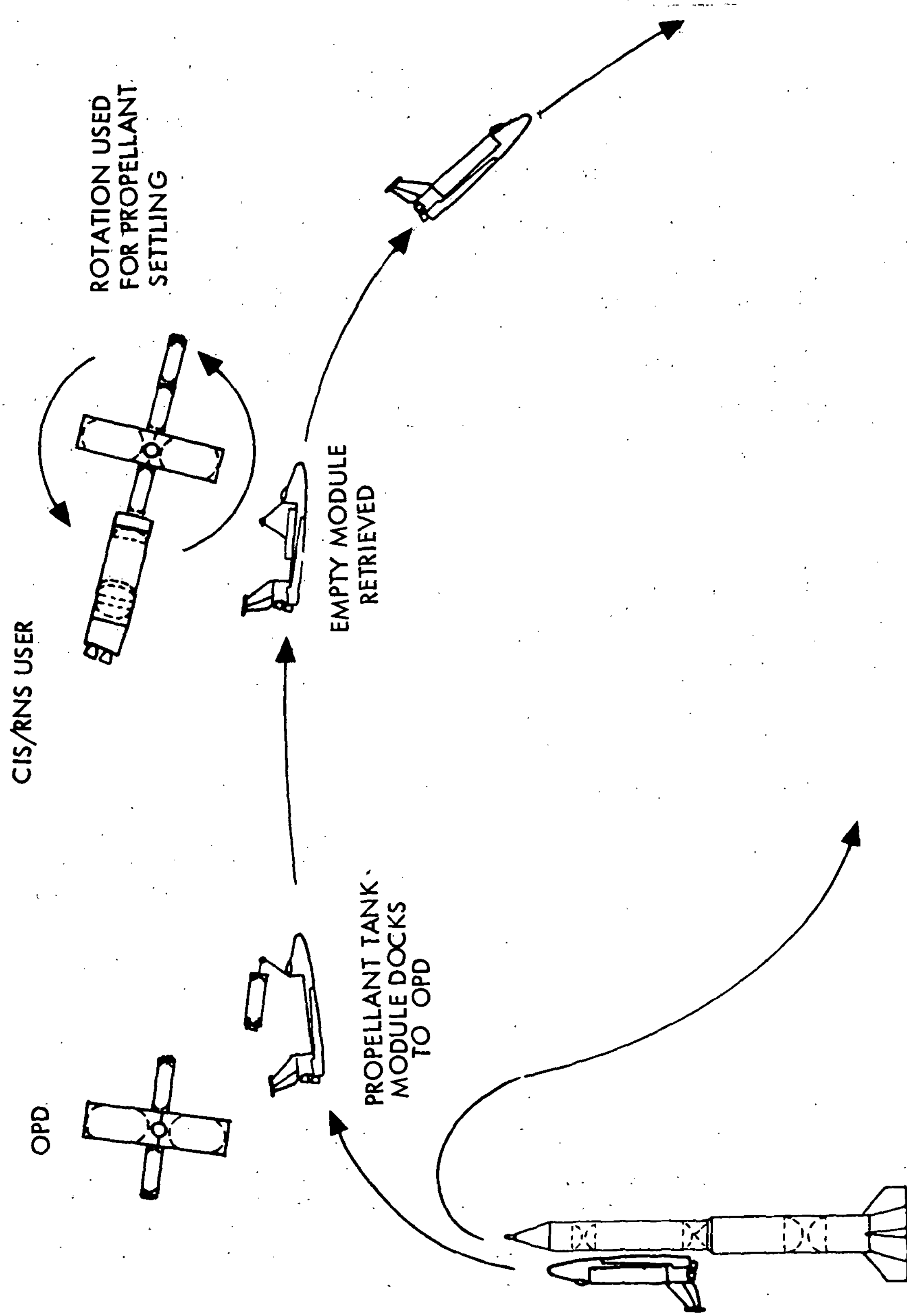


Figure B-8 Baseline Orbiter/OPD/User

Rotation for artificial g is the primary consideration leading to the storage tank and LSF module arrangement. Propellant settling by centrifugal artificial g is the baseline propellant transfer mode. The settling provides liquid-gas interface control, allowing pumping of the propellant and return of the ullage gas from the receiver tank. Initially, rotation will take place about the combined cg of the LSF and the empty user. As the mass of propellants is transferred to the user, the cg and therefore the center of rotation will shift toward the user. The symmetrical arrangement and simultaneous transfer from the opposed LH_2 tanks will maintain the cg location along the centerline of the smaller LSF modules and user vehicle. The cg will start somewhere between the LH_2 tanks and travel along that centerline toward the user. To preclude sloshing and disturbance of the propellant settling, the cg must not fall within any tank involved in the propellant transfer. Thus, the equipment module acts as a boom to extend the user tank beyond the reach of the cg excursion. The location of the LOX tank opposite to the user docking port acts as a counter balance to reduce cg travel.

The RNS is limited by cg considerations to receiving propellants from the equipment module docking port. This is also the primary docking port for tug use; although limited amounts of propellants can be transferred to tug at the other port. Because of the relatively small mass of the supply tank, propellants can be supplied to the LSF at either port. This allows the orbiter to first dock its full supply tank to one port and then retrieve the empty tank (to be returned) from the other port. If it should prove advantageous (trading off spin propellants use against boiloff from supply tanks), propellants supply transfer could be deferred until two full tanks are docked and could then be transferred simultaneously, to reduce the number of rotations. The 33 ft. diameter by 146 ft. long LH_2 tank module utilizes S-II derivative hardware. The cylindrical portion of the tanks would be of aluminum segments similar, if not identical, to those on other S-II type vehicles. The tank ends are close derivatives of the S-II hydrogen tank forward bulkhead. The outboard skirts are of similar S-II construction, as is much of the central skirt structure. Each tank holds 50,000 cu. ft. The central portion of the module contains some propellant transfer equipment and lines. In addition, the crew interface docking port is connected to the assembly joint ports with a shirtsleeve pressurable passageway. An airlock access is provided for maintenance of the transfer lines which are normally isolated from the passageway used by the maintenance crew. Pumps are located at the outboard ends of the tanks and a 4-inch transfer line inside the tank brings propellants to the center of the module.

The LOX tank module is approximately 15 ft. in diameter by 60 ft. long for compatibility with the shuttle orbiter cargo bay. The tank itself is 12 ft. in diameter by 23 ft. long with a capacity

of 2200 cu. ft. The aluminum LOX tank is suspended within the primary structure of the module. Propellant transfer lines between the tank wall and outer structure connect the propellant line interface at the docking port. Accessibility to the line interconnect and pump end of the tank is through the docking port.

The equipment module is also sized for orbiter delivery. It contains most of the subsystem equipment required for OPD operation. The basic arrangement of the module is shown in Figure B-9. The module length is based on use of the module as a boom to prevent LSF rotation about a point within the user tank. The module exceeds volumetric requirements of the presently defined equipment which will allow accessibility to the equipment for any on-board maintenance. The inboard end of the module will be a crew station. It will contain equipment for complete on-board control, monitoring and checkout of the LSF. Providing for these functions in a compartment integral to the LSF and adjacent to the equipment will be preferable to providing it remotely (telemetry) or through an interface with a visiting vehicle or maintenance module. A hatch provides access from this compartment to the remainder of the equipment module. The outboard end of the module contains the line interconnect equipment. An extendable carrier is automatically or remotely actuated to move the fluid lines and electrical lines out to meet the receptacles of the docked vehicle. The carrier and line interface is outside the docking fixture. This permits flexibility in the coordination of vehicle docking in that the same port that is used in some cases for crew and equipment transfer (having a 5 ft. diameter passage) can also be used as the propellants transfer docking port. Initial engagement of the vehicles is by the standard 7 ft. ring/cone docking fixture which draws the vehicles together into a rigidly latched and accurately aligned configuration. Engagement of the line interface is a separate operation following docking. See Figure B-10.

A crew and maintenance support module is suggested as a part of the configuration. It would be a separate module to be docked at one of the LOX tank module ports at all times when a crew is at the LSF. It would provide for all crew housekeeping activities and life support. The design of the module would share much commonality with the other crew transport modules used in the orbiter and/or the crew compartment of a manned tug. Maintenance could be performed at the outboard ends of the tanks by transferring the crew module to those docking ports, using tug or an orbiter at the time propellants are delivered. First use of the module would be during orbital assembly and checkout of the LSF.

Propellant transfer equipment will include pumps and pressurization (gas generator, heat exchanger) systems. The pumps must be located at the outboard ends of the tank where propellant is

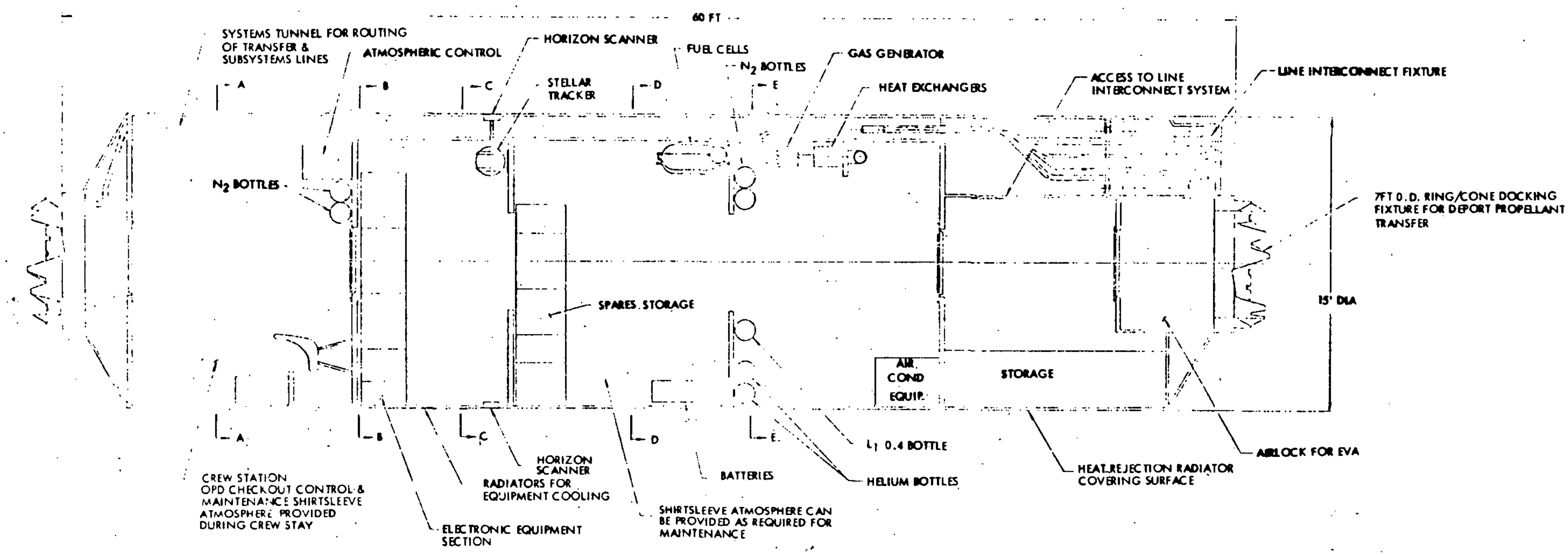


Figure B-9 Equipment Module

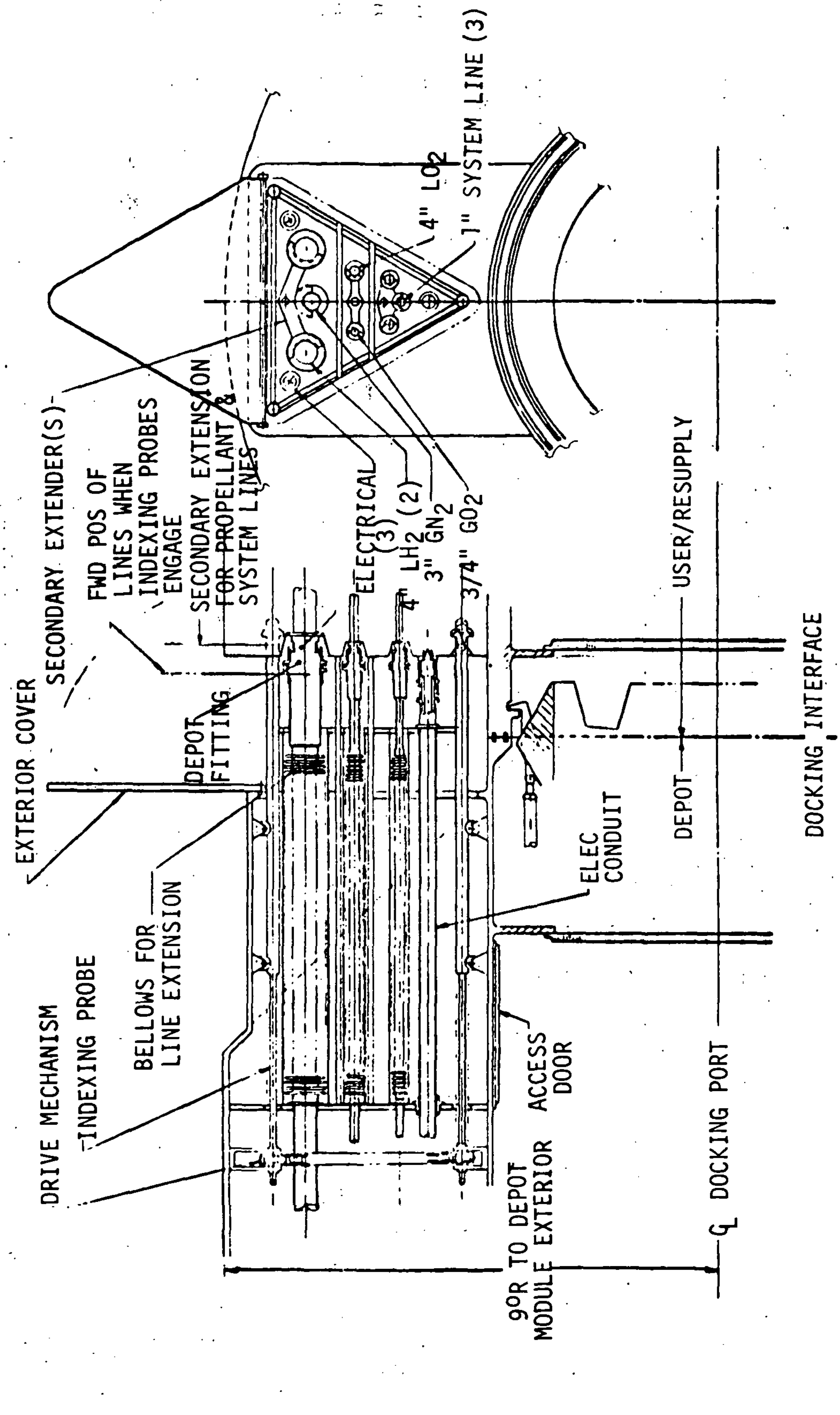


Figure B-10 Mechanical Design of OPSS Line Interconnect Fixture

settled. To facilitate maintenance and replacement, pumps will be in sumps that can be isolated and evacuated for access. Inlets to the LH_2 sumps must be located to minimize residuals. The LH_2 will settle normal to a radial line from the center of rotation. For the case where the RNS is nearly full (and LH_2 tanks low), the cg will be near the outboard end of the equipment module and propellants will not be settled normal to the centerline of the tanks. The gas generator equipment can be located in the equipment module to facilitate maintenance.

For thermal control, the tanks will be insulated and isolated as much as possible from surrounding structure. The LH_2 tank module will have HPI and meteoroid shielding external to the cylindrical portion of the module. The tank walls, which are primary structure of the module, will be separated from other structure by a low thermal conductivity skirt immediately adjacent to the tank ends.

In the central skirt section of the module the docking ports and orbital assembly joints will be exposed. The LH_2 tank ends will also be covered with HPI. The LOX tank is suspended within the module shell by low thermal conductivity struts or spokes and is surrounded by HPI. Additional insulation and thermal control will be provided for maintenance crew occupancy of portions of the modules. It is expected that some thermal control (coldplating) will be required for subsystems equipment.

Attitude control jets are located on the outboard ends of the LH_2 tank module. Thrust for propellant settling spin up and despin is provided by the ACS and the outboard location provides maximum moment arm for this. The two ACS modules would attach to outboard ends of the tank modules using standard docking hardware and would provide for docking at its outboard end. Internal access would allow some in-orbit maintenance and the entire module can be replaced and returned in the shuttle to earth for refurbishment. Docking and access to the pump package is also provided through the center of the ACS module.

Maintenance considerations have been included in the concept and development of the LSF. Accessibility has been mentioned in the previous descriptions of each module; it is intended that almost all areas external to the tanks and all equipment where ten-year reliability is difficult to achieve would be accessible. The crew interface compartment and passageway from the crew docking port would provide shirtsleeve environment. If possible, equipment subject to frequent on-board maintenance would be located here. The other internal areas of the modules would be accessible, but where maintenance is infrequent and where construction permitting environmental control (especially long-term pressurization) would be costly, it should be sufficient to provice only for suited IVA with slight pressurization to improve suit mobility. No in-orbit access inside any of the storage

tanks is being considered. The LOX tank module and the equipment module can be considered or the tradeoff can be made to determine whether the high maintenance equipment such as fuel cells and batteries, which might require frequent replacement, should be grouped and the equipment module designed in two segments with scheduled replacement of one segment rather than the whole module. It is the intent that little or none of the maintenance will require EVA. On-board maintenance will be limited to relatively simple remove and replace tasks with a modular approach used in equipment installation to facilitate replacement. Installations will be designed to simplify maintenance tasks and provisions such as handling aids will be incorporated.

The launch concept calls for the LH_2 tank structure to be launched as a single payload using an SS booster and an ESS.

b. Propellant Transfer System

Each major component of the propellant transfer system is identified by a number in Figure B-11, which in turn is defined in Tables B-1 through B-5. It is recognized that redundancy of some components will be required, but for purposes of this schematic they are not included. The configuration of each propellant transfer subsystem is discussed below.

(1) Liquid/Vapor Interface Control

Liquid/vapor interface control is provided by centrifugal acceleration imparted to the propellants by rotation of the combined LSF and user vehicle. The attitude control jets will supply the thrust for rotational spin-up and spin-down. To minimize liquid/vapor interface distortion (ullage gas pull through) during propellant feedout and therefore minimize the liquid remaining at transfer termination, a tank outlet sump with baffles and screens will be provided. This may be integrated into a pump package configuration. Antislosh baffles and capillary screens will also be utilized in the vicinity of the transfer pump inlet and throughout the tank as a secondary means of liquid/vapor interface control during either propellant feedout or refill operations. Guide vanes will be needed at the pump inlet to provide minimum fluid disturbance and maximum pump efficiency.

(2) Receiver Tank Thermodynamic Control

Prior to a propellant transfer, the chilldown of the transfer lines and receiving vehicle tankage will be achieved by reduced liquid flow provided by the slow fill pumps or by throttled flow utilizing the individual tank flow control valves. The vapor generated by chilldown will be used to supplement ullage pressurant flow. The ullages of the LSF

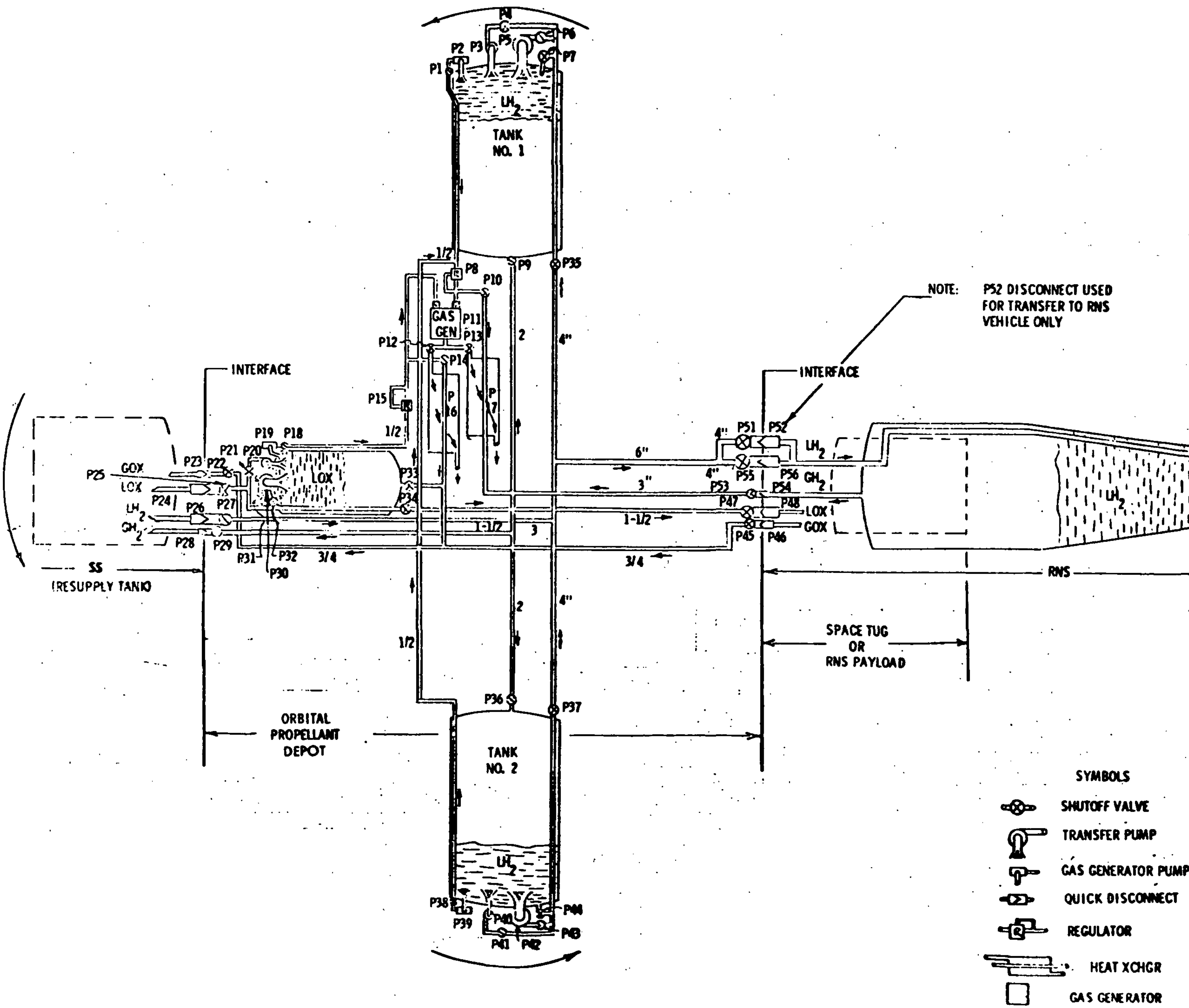


Figure B-11 Schematic Representation of RNS Baseline Propellant Transfer System

Table B-1 Propellant Transfer System Pumps

NAME	"P" NO.	LIFE YRS	SIZE IN	WT #	FLOW #/HR	MEDIA	PRESS PSIA	TEMP °R
G G LH_2 PUMP	2	10	1/2	2	TBD	LH_2	TBD	37
SLOW FILL LH_2 PUMP	3	10	2	10	6000	LH_2	20	37
MAIN LH PUMP	5	10	4	25	15000	LH_2	20	37
GG LH PUMP	39	10	1/2	2	TBD	LH_2	TBD	37
SLOW FILL LH PUMP	40	10	2	10	6000	LH_2	20	37
MAIN LH PUMP	42	10	4	25	15000	LH_2	20	37
GG LOX PUMP	19	10	1/2	2	TBD	LOX	TBD	163
SLOW FILL LOX PUMP	20	10	1	1-1/2	1200	LOX	20	163
MAIN LOX PUMP	30	10	1-1/2	15	12000	LOX	20	163

Table B-2 Propellant Transfer System Pump Characteristics

PUMP NO. PUMP NAME	P3 & P40 SLOW FILL LH_2	P5 & P42 MAIN LH	P30 MAIN LOX
PRESSURE RISE, PSI	6	3	5
SPEC SPEED	2000	1180	2000
HORSEPOWER	3/4	1-1/2	1/8
PUMP DISCHARGE DIA	2	4	1.5
FLOW DATA #/HR	6000	15000	12000
RPM	8000	1800	2500
FLUID	LH_2	LH_2	LOX

Table B-3 Propellant Transfer System Disconnects

NAME	"P" NO.	LIFE YRS	SIZE IN	WT LBS	MEDIA	PRESS PSIA	TEMP °R
SS GOX DISCONNECT	23	10	3/4	1	GOX	20	163
SS LOX DISCONNECT	24	10	1-1/2	2-1/2	LOX	20	163
SS LH_2 DISCONNECT	26	10	4	8	LH_2	20	37
SS GH_2 DISCONNECT	28	10	3	5	GH_2	20	37
TUG GOX DISCONNECT	46	10	3/4	1	GOX	20	163
TUG LOX DISCONNECT	48	10	1-1/2	2-1/2	LOX	20	163
RNS LH_2 DISCONNECT	52	10	4	8	LH_2	20	37
RNS GH_2 DISCONNECT	54	10	3	5	GH_2	20	37
RNS/TUG LH_2 DISCONNECT	56	10	4	8	LH_2	20	37

Table B-4 Propellant Transfer Gas Generator System

NAME	"P" NO.	LIFE YRS	SIZE IN	WT LBS	MEDIA	PRESS PSIA	TEMP °R
GAS GENERATOR	11	5	N/A	8	LOX/LH_2 1:1	TBD	TBD
LH_2 REGULATOR	8	10	1/2	1-1/2	LH_2	TBD	TBD
LOX REGULATOR	15	10	1/2	1-1/2	LOX	TBD	TBD
LOX HEAT EXCHANGER	16	10	N/A	25	LOX	20	TBD
LH_2 HEAT EXCHANGER	45	10	N/A	25	LH_2	20	TBD

Table B-5 Propellant Transfer System Valves

	"P" NO	LIFE YRS	SIZE IN	WT LBS	MEDIA	PRESS PSIA	TEMP °R
LH_2 SHUTOFF VALVE SS DISCONN.	27	10	4	15	LH_2	20	37
GH_2 SHUTOFF VALVE SS DISCONN.	29	10	3	8	GH_2	20	37
SHUTOFF VALVE MAIN LOX PUMP	31	10	1-1/2	5	LOX	20	163
RESUPPLY VALVE LOX TANK	32	10	3	8	LOX	20	163
GOX ULLAGE SHUTOFF VALVE	33	10	3/4	1	GOX	20	163
LOX TANK MAIN SHUTOFF VALVE	34	10	1-1/2	3	LOX	20	163
LH_2 FLOW CONTROL VALVE #1	35	10	4	15	LH_2	20	37
GH_2 ULLAGE SHUTOFF VALVE	36	10	2	5	GH_2	20	37
LH_2 TANK MAIN SHUTOFF VALVE #2	37	10	4	15	LH_2	20	37
GG SHUTOFF VALVE LH_2 TANK	38	10	1/2	1/2	LH_2	20	37
SLOW FILL SHUTOFF VALVE LH_2 TANK	41	10	2	5	LH_2	20	37
SHUTOFF VALVE MAIN LH_2 PUMP	43	10	4	15	LH_2	20	37
RESUPPLY VALVE LH_2 TANK	44	10	4	15	LH_2	20	37
TUG GOX DISCONN. SHUTOFF VALVE	45	10	3/4	1	GOX	20	163
GG SHUTOFF VALVE LH_2 TANK	1	10	1/2	1/2	LH_2	TBD	37
SLOW FILL SHUTOFF VALVE LH_2 TANK	4	10	2	5	LH_2	20	37
SHUTOFF VALVE MAIN LH_2 PUMP	6	10	4	15	LH_2	20	37
RESUPPLY VALVE LH_2 TANK	7	10	4	15	LH_2	20	37
GH_2 ULLAGE SHUTOFF VALVE	9	10	2	5	GH_2	20	37
GH_2 PRESSURIZATION SHUTOFF	10	10	3	8	GH_2	20	37
HOT GAS VALVE LOX HEAT EXCHANGER	12	10	3	8	GOX	TBD	TBD
HOT GAS VALVE LH_2 HEAT EXCHANGER	13	10	3	8	GH_2	20	37
LOX PRESSURIZATION SHUTOFF VALVE	14	10	1/4	1/2	LOX	20	163
GG SHUTOFF VALVE LOX TANK	18	10	1/4	1/2	LOX	20	163
SLOW FILL SHUTOFF VALVE LOX TANK	21	10	1	1-1/2	LOX	20	163
GOX SHUTOFF VALVE SS DISCONN.	22	10	3/4	1/2	GOX	20	163
LOX SHUTOFF VALVE SS DISCONN.	25	10	1-1/2	3	LOX	20	163
TUG LOX DISCONN. SHUTOFF VALVE	47	10	1-1/2	3	LOX	20	163
TUG LH_2 DISCONN. SHUTOFF VALVE	51	10	4	8	LH_2	20	37
RNS GH_2 DISCONN. SHUTOFF VALVE	53	10	3	8	GH_2	20	37
RNS LH_2 DISCONN. SHUTOFF VALVE	55	10	4	25	LH_2	20	37

and user vehicle will be connected during the entire propellant transfer operation. For the LH_2 system the vapor will return from the receiver vehicle through a 3-inch disconnect and 3-inch lines from the docking port interface to the center of the LSF vehicle. There, it will subdivide into two 2-inch diameter lines, one line routed to each of the LSF LH_2 tank ullages. For the LOX system, the vapor will be routed through a 3/4 inch disconnect at the docking port interface to 3/4 inch lines which are in turn routed to the ullage at the center of the LSF.

If ullage pressure exceeds the design limit, shower heads located in the ullage area of the receiving vehicle will be used to spray a portion of the incoming liquid propellant into the ullage vapor. In this manner, a partial control of tank pressure and temperature will be achieved by heat transfer between incoming cold liquid droplets and the relatively warm ullage vapor. A thermodynamic vent system will also be available as a supplementary ullage control.

(3) Expulsion

Each of the three main propellant storage tanks (two opposing LH_2 tanks and one LOX tank) of the LSF will have a pump package. The pump package will be located at the tank end away from the center of rotation. Each pump package will consist of a high capacity transfer pump (fast fill pump), a low capacity transfer pump (slow fill pump) and a relatively high pressure pump for use with the pressurization system heat exchanger and gas generator. The transfer pump package must be located at the tank bottom so that it will be continuously covered with propellant during the center of gravity migration inherent with transfer operation.

LH_2 will be transferred from the pump package on each of the two LH_2 tanks to the user vehicle. A 4-inch diameter line will be utilized from each LH_2 tank pump to the center of the LSF. A single 6-inch diameter line from the 4-inch line junction will be routed to the docking port at the extreme end of the equipment module. The equipment module opposes the LOX storage tank. The 6-inch diameter transfer line will then subdivide into two parallel 4-inch disconnects at the docking port interface. Both 4-inch disconnects are required for a RNS propellant transfer; however, only one disconnect is required for transfer to the tug. This avoids the weight penalty of a second (or larger than required) disconnect on the smaller vehicles.

Each of the two 4-inch transfer lines will have a flow control valve which is used to balance the load between the two LH_2 storage tanks. This provides some control over the center of gravity of the mated vehicles. The flow control

valves will also be used as required in addition to the slow fill pumps to reduce the total flow rate during chill or residual minimization throttling operations.

LOX will be transferred from the pump package on the LOX tank toward the center of the LSF by a 1-1/2 inch diameter line. This line will extend to the docking port at the extreme end of the equipment module. A 1-1/2 inch disconnect is utilized at the interface.

A second docking port, similar to the docking port on the equipment module will be located at the outboard side of the LOX storage tank. Although all space vehicles can be docked at either of the interface ports, the baseline RNS can only be serviced completely at the equipment module docking port. This is because the equipment module must act as a boom to prevent the center of rotation from entering the RNS propellant tank during RNS transfer operations. For this reason, only one 4-inch LH_2 interface disconnect will be required on the LOX module docking port. Propellant transfer operations with the tug can be accomplished equally well at either interface port.

The interface disconnect sizes for LH_2 propellant transfer and vapor return were selected to accommodate the RNS. The interface disconnect sizes for LOX propellant transfer were selected to accommodate the tug. Therefore, the LH_2 4-inch disconnect at the LOX tank docking port interface is connected to the LH_2 tank transfer system by a 3-inch diameter line, the LH_2 3-inch vapor return disconnect at the LOX tank docking port is connected to the LH_2 vapor return system by a 1-1/2 inch diameter line.

(4) Pressurization

Ullage pressurization required prior to propellant transfer will be accomplished with a single gas generator. The pressurization is necessary to prevent the formation of vapor in the transfer system. The gas generator will supply a heat exchanger for each of the two transfer systems (LH_2 and LOX). A pump in the pump package of each tank will supply the liquid propellant to the gas generator and heat exchangers. The two 1/2 inch diameter gas generator supply lines from the LH_2 tanks will be routed through a single regulator. The regulated output will then separate to supply the gas generator and the LH_2 pressurant inlet to the heat exchanger. The gas generator will supply hot gas to the heat exchanger for vaporization of the hydrogen pressurant. The vaporized pressurant is then routed to the LH_2 tank ullages of the LSF and interfacing vehicle. The single 1/2 inch diameter line from the LOX GG pump is routed through a regulator to the gas generator and LOX heat exchanger in

a manner similar to that for the LH_2 pressurization system. The vaporized pressurant is then routed to the LOX tank ullages of the LSF and interfacing vehicle. After passing through the heat exchangers, the products of the gas generator are vented into space.

Transfer line valves will be arranged so that the propellant storage tanks can deliver and receive propellants through a common system of transfer lines and vapor return lines. The pumps used for propellant transfer will be mounted in the tanks. This will minimize the ullage pressure required for pump NPSH by eliminating suction line pressure losses upstream of the transfer pump. The ullage pressurization systems on the LSF will be used to pressurize all tanks including resupply tanks.

c. CIS Baseline Vehicle

The CIS baseline vehicle considered as an alternate for the RNS baseline vehicle requires a 6-inch diameter LOX and LH_2 propellant transfer system. It is anticipated that the two 4-inch disconnects for LH_2 transfer to the RNS can be utilized for the CIS baseline. Further, it is anticipated that the same two 4-inch disconnects planned for LH_2 transfer system design can be utilized for LOX transfer to the CIS baseline vehicle.

5. Conceptual Tug and Applicable Systems Used in FMEA

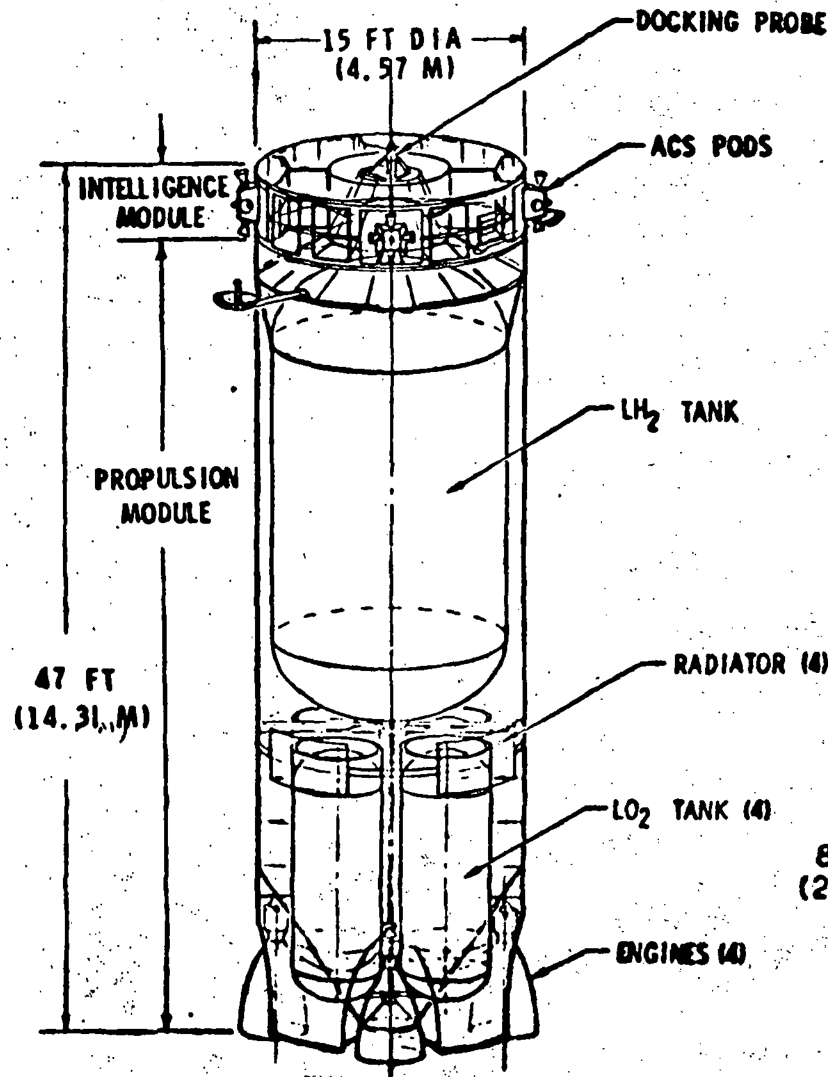
The basic conceptual configuration of the tug as involved in this safety study is presented in Figure B-12. The conceptual description of tug subsystems follows.

a. Guidance, Navigation and Control Subsystem

The GN&C system components of the space tug are briefly described here for the intelligence module basic GN&C equipment, crew module basic GN&C equipment and rendezvous and docking GN&C equipment.

(1) Intelligence Module Basic GN&C Equipment

The IM basic equipment consists of an IMU with associated preprocessor, gimbaled star trackers for attitude reference, sun sensors for attitude acquisition and sun pointing attitude hold, horizon tracker(s) for navigation measurements up to geosynchronous altitude, and navigation sensor base for the star trackers and IMU. For adequate fields of view for the star trackers while making horizon tracker measurements in low earth orbit, the horizon tracker(s) is mounted on the opposite side of the IM from the navigation base and sensors.



WEIGHTS:

STAGE INERT	10,200 LB (4,620 KG)
USABLE PROP	73,200 LB (33,200 KG)
GROSS WT	83,400 LB (37,820 KG)

PROPELLANTS:

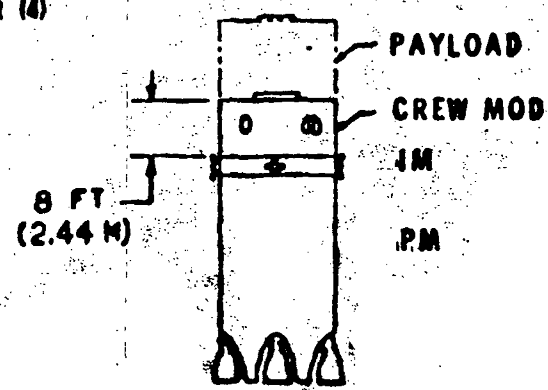
LO_2: LH_2 6:1

PERFORMANCE:

ENG TYPE (NEW)	
THRUST (EA)	9,000 LB (4,080 KG)
ISP	463 SECONDS
MASS FRACTION	.873

DOCKING: APOLLO: { PROBE FWD / DROGUE AFT

TUG WITH CREW MODULE



CREW MODULE:

WEIGHT: 8,700 LB
(3,950 KG)

DOCKING:
7' NEUTER FWD
APOLLO DROGUE AFT

Figure B-12 Space Based Tug

The IM also contains the electronics for controlling the ACS reaction jets (ACS driver amplifiers) and the main engine gimbals and throttling (engine gimbal amplifiers).

In addition to this equipment the GN&C system will use the computers, central timing unit, data bus, and signal conditioning units, which are part of the communications and data management system.

Most GN&C signals, commands, and data within the IM will be carried on the data bus as part of the C&DM system. Some signals and commands to the reaction jets and main engines will be carried on separate wires.

(2) Crew Module Basic GN&C Equipment

The crew module basic GN&C equipment consists of rotation and translation controllers to manually control the space tug with the ACS reaction jets; a triad of attitude/rate gyros and a longitudinal integrating accelerometer mounted on the telescope base to provide a backup attitude control and manual thrust maneuver control system; a semi-automatic telescope with pointing controls and base for navigation sightings and lunar landing site tracking; manual control electronics; an ACS control mode selection panel; and a GN&C power control panel. The rotation controllers are also used to manually control the main engine gimbals, through the manual control electronics unit, during manual thrust maneuvers.

In addition to the components above, the crew will use for GN&C operations the alphanumeric and multi-format graphics displays and the two keyboards for requesting displays or entering data into the computer. The displays and keyboards are part of the C&DM System.

(3) Rendezvous and Docking GN&C Equipment

Sensors required for rendezvous and docking are a rendezvous and docking radar mounted on the docking face for target acquisition, tracking, and automatic docking; a docking television camera, also mounted on the docking face, for crew or ground monitoring of automatic docking and manual completion of docking if necessary; and contact sensors to indicate when latching of the docking mechanism has been completed.

Equipment required on target vehicles consists of corner reflectors or a laser radar transponder mounted on the docking face, and visual docking aids, consisting of a distinctive pattern, standoff cross, etc., on the docking face to provide visual cues for manual docking. Non-

cooperative rendezvous can be accomplished only by adding a skin-tracking rendezvous radar to the tug or part of the payload.

b. Communications and Data Management Subsystem

The communications and data management subsystem provides the capability for acquisition, processing, storage, and both internal and external exchange of information related to tug checkout, monitoring, and operations. The subsystem supports the mission concepts without re-configuration within individual modules, with the exception of software.

(1) Communications

Communications parameters establishing requirements for transmitter power, antennas, receivers, and operational limitations include the information rates and quality (required signalto-noise ratio, or error rates) and the geometry of the links. Four classes of information are provided for the tug missions. A low data rate capability includes commands, tracking information, gears status measurements, and voice. This link would be capable of data rates up to ≈4000 bits per second.

Moderate rates are required for remote monitoring of vehicle subsystems' response to commands or status during critical periods, checkout routines and dumps of stored data. Rates are assumed up to 500,000 bits per second.

Television capability equivalent to that on Apollo provides a general video monitoring capability for overall situation assessment. The link capacity also could be used for high speed data dumps or for simultaneous transmission of several channels of data over the link.

(2) Data Management

The major requirements affecting the data management are rates, information storage requirements, and subsystem interfaces.

The operational memory includes the rapid access (nanoseconds) programs required for essentially real time control of the subsystem, including data management. Mass memory includes programs which are accessible in milliseconds. It is supplemental to the operational memory and stores long term operational programs, alternatives, data for long term analysis, and any special mission information.

(3) Link Frequencies

Frequency selection is optimized in terms of power, bandwidth, coverage, and antenna requirements. The frequency spectrum is heavily assigned and utilized, with both international and Government agreement required for operation in specific frequency ranges. Earth and moon programs will apparently still be largely using S-Band frequencies in the vicinity of 2.3 GH_2. The TDRS link may be either S or Ku (around 13.5 GH_2) band.

(4) Antennas

Omni-directional antennas will provide adequate gain for low data rate links, and for high data rates at shorter ranges. Directional antennas will be required for longer ranges and for relative angle measurements. The parabolic design is the choice for this concept.

(5) Tracking

The tracking subsystem includes the capability to transpond a ranging signal from the MSFN or other space elements, and to perform ranging on cooperative targets as well as determine relative bearings to the target. This capability is good to within 1000 feet. Closer approaches will be supported by the GN&C subsystem with a laser radar or by video camera assigned to the GN&C.

(6) Multiplexing

Video and voice are basically analog signals which lend themselves to frequency division multiplexing (FDM), unless a very large number of channels are involved. The tug will have a small number of such channels and will not approach the complexity required to consider time division multiplex (TDM). The digital signals are inherently TDM.

(7) Storage

Operating and mass memory will be the plated wire. It should be noted that scratchpad memories within the processor probably will be solid state to achieve the high speed needed.

Archival memory consists of long-term records of data samples, alternate programs for mass memory, collections of unprocessed data for later transmission to the MSFN, or other information for which access is not time-critical. Tape machines are used for this type of storage on the tug.

c. Electrical Power Subsystem

Two fuel cells will provide the voltage regulation and redundancy capability for the main power subsystem for unmanned missions. Two 3-phase, 400 Hertz inverters are included for alternating current (AC) loads in the otherwise direct current (DC) power subsystem configuration. Two secondary peaking batteries will supplement the fuel cells for peak loads and emergency power requirements. Power will be distributed to decentralized power control centers throughout the vehicle with due regard for electromagnetic compatibility considerations. Solid-state switching devices and circuit breakers will be used for switching and control where practical. Cooling of solid-state conversion equipment and batteries will be effected through mounting on cold plates. Fuel-cell cooling will be effected through the tug heat injection radiator loops.

d. ACPS Subsystem

The ACPS is a pump-fed system utilizing gaseous oxygen and gaseous hydrogen, which has a capillary device in the main tanks for liquid feed to the pumps. Four engines with 200-pound thrust engines throttable to 40 pounds thrust are provided. Accumulators provide 20 seconds of propellant to the engines. The conditioning unit response time is 5 seconds.

(1) Capillary Device

The capillary device in the main tanks will supply 200 lbs. of propellant to the ACPS between any two, or after the last main engine burns.

An umbrella-type dutch twill screen of 30 by 250 mesh with pore openings of 0.00276 inch assures propellant retention, but provides sufficient opening for low pressure loss during propellant flow and for rapid refilling. The retention screen is mounted on a conical frame for strength, refilling and bubble purging during main engine burn. For adequate refilling of the compartment, the half cone angle should not exceed 80 degrees.

(2) Propellant Acquisition and Expulsion

A propellant collector is provided within the retention compartment and provides two pounds per second flow rate, collects propellant after gas breaks through into the compartment, and prevents gas passage into the collector.

(3) Tankage

The common tankage system includes a supply of cryogenics for main propulsion and a liquid-to-gas conversion system for ACS, EPS and ECLSS.

Liquid oxygen and liquid hydrogen are stored in main tanks at 20 psia. After conversion, the gases are stored in the accumulators at 350 to 1000 psia. Through regulators, pressure is lowered to 300 psia for ACPS, 50 to 1000 psia for the EPS, and 5.5 to 14.7 psia for the ECLSS. In the crew module, an intermediate oxygen storage container is provided at the accumulator pressure.

e. Docking Subsystem

An Apollo docking system is used for the tug with the probe being forward and the drogue located aft inboard of the main engines.

6. Centaur Systems Used in FMEA

The conceptual Centaur configuration used in the representative propellant logistic operations is based on the Centaur version as contained in the General Dynamics Centaur/Shuttle Integration Report #GDC-BNZ70-024. Figure B-13 illustrates the basic Centaur configuration.

a. Tanks and Structure

The tank structure consists of a thin-walled, 301 stainless steel, monocoque cylindrical section, capped at both ends by stainless steel bulkheads. A double-walled, insulated, ellipsoidal inner bulkhead provides separation between the liquid oxygen (LO_2) tank and the liquid hydrogen (LH_2) tank.

The payload support structure on Centaur is designed for 12,000-pound payloads, carrying them on a truss structure with a 10-foot interface diameter. Payloads weighing less than 5,000 pounds can be carried on the equipment module with a 65.92-inch-diameter bolt circle.

b. Main Engine System

Primary vehicle thrust is provided by two Pratt & Whitney RL10A-3-3 engines which are capable of performing multiple starts in space, and have the following performance characteristics.

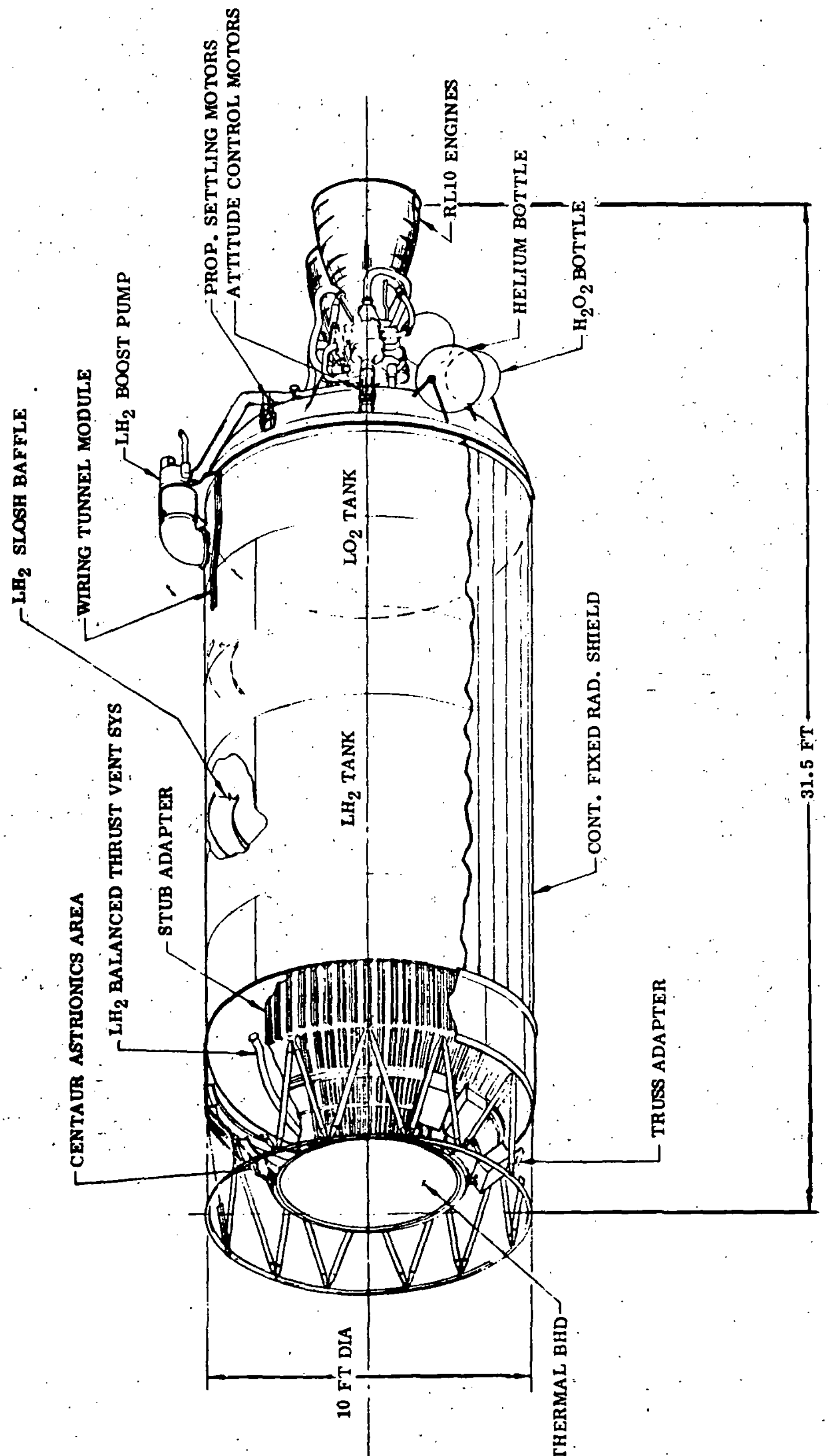


Figure B-13 Centaur Configuration

Thrust (nominal)	15,000 lb
Chamber Pressure	400 psia
Mixture Ratio (nominal)	5:1
Specific Impulse, I_{sp} (nominal)	444 sec
Rated Operating Duration (per firing)	450 sec

c. Tank Pressurization

The airborne tank pressurization subsystem consists of the helium storage bottle, tubing, and the various check valves, restrictors, and shutoff valves required to deliver pressurized helium from the storage bottle to the tanks. Vent valves on the propellant tanks prevent overpressurization of the tanks.

Prior to tanking, propellant tanks are pressurized directly from ground-supplied helium. At the start of tanking, boiloff provides pressurization which is regulated by vent (boiloff) valves on each tank. Fuel tank pressure is nominally 21 psia; oxidizer tank pressure is 30 psia.

Propellant tank pressurization is increased prior to each main engine start to prevent boost-pump cavitation by increasing the net positive suction head. Vent cycles are required at about two-hour intervals on long coasts.

d. Propellant Feed

The propellant feed system consists of fuel and oxidizer sump-mounted boost pumps, propellant feed ducts, and recirculation lines to maintain liquid at the engine inlet shutoff valves. Propellant flow is initiated by a centrifugal-flow boost pump submerged in each propellant tank. See Figure B-14.

e. Propellant Utilization System

The propellant utilization (PU) system adjusts the propellant mixture ratio of the main engines to ensure that propellant residuals at the termination of powered flight are at a minimum. Control is achieved by varying oxidizer flow through the engines as a function of the propellant masses remaining in the vehicle tanks.

The PU system consists of five major components: fuel and oxidizer tank propellant sensors (capacitance probes), an electronics package, and two servo-positioners.

f. Thermal Control

The cylindrical portion of the liquid hydrogen tank is insulated by a radiation shield consisting of three layers of aluminized Mylar. The shield is effective against solar heating and earth radiation and improves the capability of the Centaur to perform

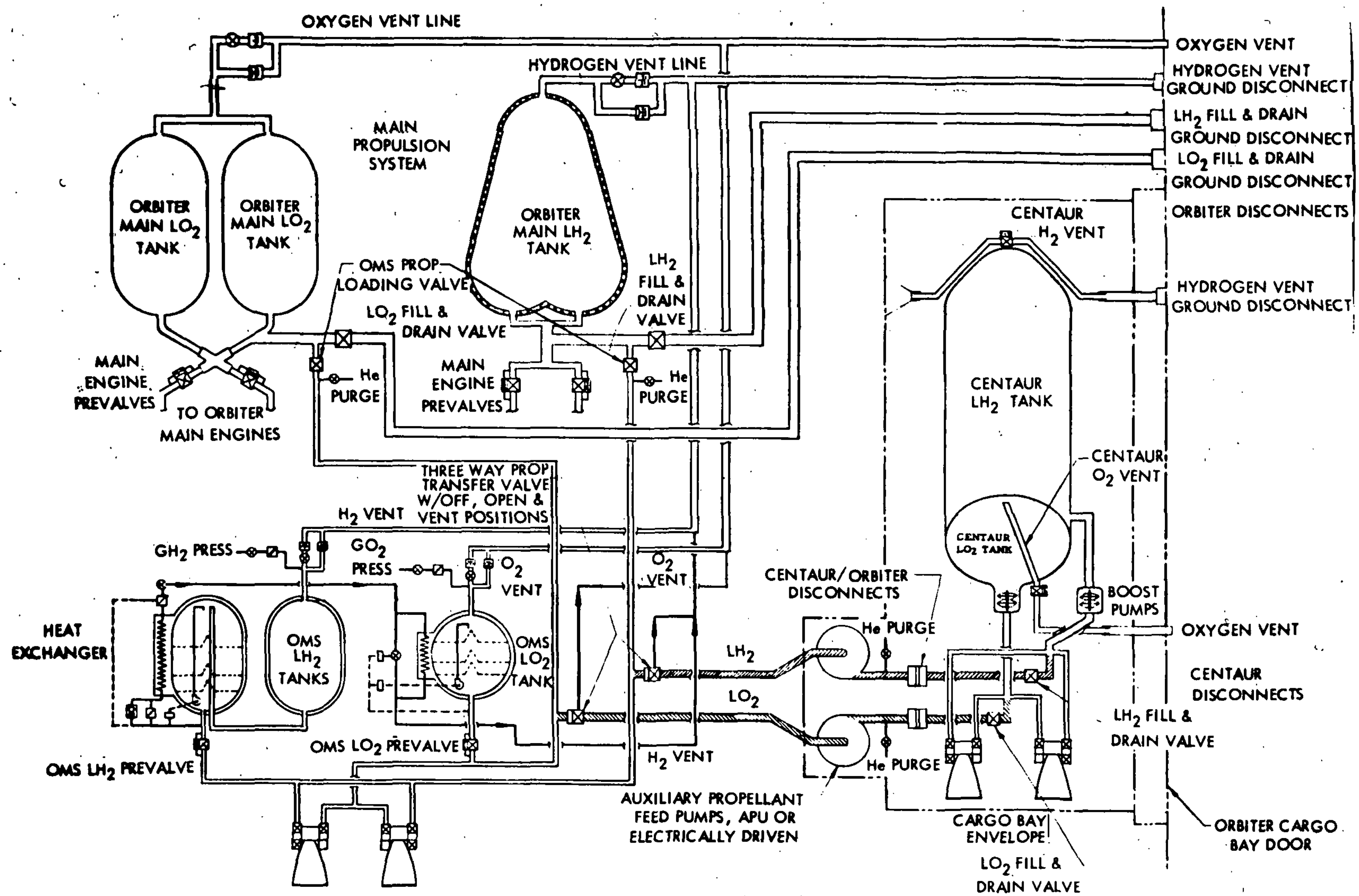


Figure B-14 Combined Tanking, OMS-Out by Auxiliary Pumps, Abort thru Orbiter with Centaur Boost Pumps

long-coast missions by reducing hydrogen boiloff significantly. The shield reduces sidewall heating by a factor of over 40 compared to bare walls, which reduces total hydrogen tank heat input (including bulkheads) by a factor of 10. The shielding arrangement results in propellant tank maximum extended operation heating rates of approximately 3080 BTU/hr and 2070 BTU/hr for the LH_2 and LO_2 tanks respectively.

g. Astrionics

The Centaur Astrionics System consists of the following units:

Digital Computer Unit - DCU
Inertial Measurement Group
Sequence Control Unit
Servo Inverter Unit
Propellant Utilization

(1) A simplified block diagram of the system appears in Figure B-15. The DCU is a stored program digital computer with a 16,384 word by 24 bit ferrite core memory.

(2) The Inertial Measurement Group in conjunction with the DCU makes up the Centaur vehicle inertial guidance system. The IMG consists of the Inertial Reference Unit (Platform) and the System Electronics Unit and provides vehicle velocity data to the DCU and transforms inertial coordinates to vehicle coordinate.

(3) The Sequence Control Unit provides prelaunch and inflight control of the vehicle systems and contains a relay switch section, a decoder section and a power switch section.

(4) The Servo Inverter Unit provides control of the engine actuators by signals from the DCU. It also contains a power conversion section for providing AC power by the vehicle systems.

(5) The Propellant Utilization system provides inflight control of the propellant masses to minimize end residuals.

h. Electrical System

The Centaur electrical system supplies and distributes 28-volt DC power, and distributes 115-volt and 26-volt, single phase, 400-H_z AC power to the various Centaur systems during checkout, countdown, and flight operations. It provides remote internal/external power changeover switching and remote safety function safe and arm switching capability.

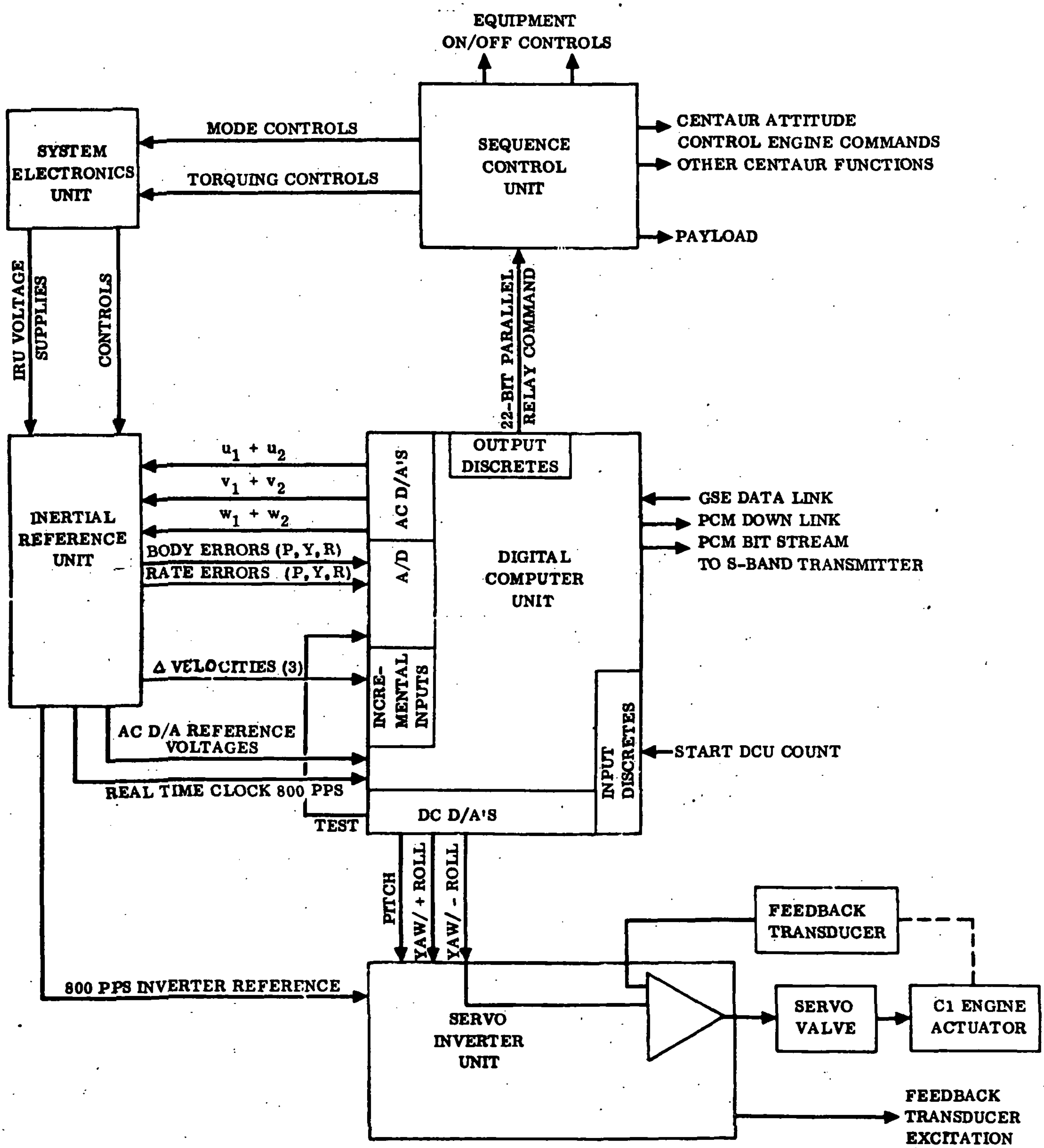


Figure B-15 Astrionics System

i. Emergency Propellant Dump System

Abort Requirements - The Centaur must be able to dump its propellants during an emergency abort situation in order to prevent landing the shuttle orbiter with a fully loaded stage in the cargo bay. In order to accomplish this the fill and drain lines have been increased to 6-inch diameter and provisions made to pressurize the propellant tanks to the allowable maximum (44 psia in the LO_2 tank and 29 psia in the LH_2 tank). The assumed vapor pressure for the propellants is 20 and 30 for the LO_2 and LH_2 respectively, giving available driving ΔP's of 9 psia for LH_2 dumping and 14 for LO_2 dumping. If both dump lines (i.e., fill and drain) are increased in size to 6-inch diameter the LO_2 can be dumped in approximately 70 seconds and the LH_2 in approximately 60 seconds. The propellants should be dumped sequentially during an abort situation, requiring just over 2 minutes for the entire dump process. Approximately 900 lb_f and 1200 lb_f thrust will be generated by the LH_2 and LO_2 vent fluid.

In order to maintain the desired tank pressures during emergency abort it is necessary to provide helium pressurant which is carried in the cargo bay specifically for this purpose. This helium is stored in five 27.25 inch spherical bottles which contain a total of 30 cubic feet of ambient temperature helium at 3000 psi. They are plumbed into the tank pressurization system via the two ground lines passing through the T-4 panel, and are filled during countdown by a tee from the helium charge line which also passes through the T-4 panel. This supply is also used to open the Centaur fill and drain valves to permit propellant dumping. Helium must be supplied at 800 psi to open these valves. Since the main helium supply bottle pressure decays to approximately 100 psi at the completion of propellant dump, a separate reservoir is needed to maintain a high fill and drain valve supply pressure during the final dumping phase.

7. Failure Mode and Effects Analysis Sheets

The FMEA for the Representative Orbital Propellant Logistic baseline and both tug and ESS variations are contained on the following sheets. As in the case of FFD identification, the FMEA sheets for the tug variations for delivery function sharing is coded with an A. The ESS/large propellant tank variation for propellant delivery to a CIS/RNS is coded with a B.

MISSION PHASE - PRELAUNCH PROGRAM ISPLS FMEA NO. 2.3.4.3

REF. FFBD	OPERATIONAL STEP	ITEM NO.	FAILURE MODE	FAILURE EFFECT A - System C - Mission B - Subsystem D - Personnel	HAZARD IDENTIFIED Yes/No	PRIMARY CAUSE
2.3	Prepare support equipment and propellant storage area		Facility line rupture	A Damage to storage tank by implosion/fire	Yes	Loss of shutoff valve and insufficient ullage makeup pressure.
				B Mass spill through line	Yes	Overstress of line during childown
				C Delay of mission	No	
				D Fire/Explosion	Yes	Ignited propellants

Temp-S-3168

MISSION PHASE - PRELAUNCH PROGRAM ISPLS FMEA NO. 2.3.4.6

REF. FFBD	OPERATIONAL STEP	ITEM NO.	FAILURE MODE	FAILURE EFFECT A - System C - Mission B - Subsystem D - Personnel	HAZARD IDENTIFIED Yes/No	PRIMARY CAUSE
2.3	Stow perishables and hazardous cargo (Hydrazine N_2H_4) (LN_2)	1	Leaking propellant or pressurant tankage	A Corrosive (N_2H_4)	Yes	Damage during loading
				B Render unusable in space environment	Yes	Vapors from N_2H_4
				C Delay of mission	No	Vapors contaminating environment
				D_1 Toxic/corrosive fumes contaminating cargo bay/work areas (N_2H_4)	Yes	Vapors from leaking N_2H_4
				D_2 Thermal (LN_2), Fire or Explosion (N_2H_4)	Yes	Leaking cryogen or spraying fuel
				D_3 Displacement of oxygen in environment (LN_2).	Yes	Confinement of LN_2 causing oxygen displacement or dilutant

Temp-S-3168

REF. FFBD	OPERATIONAL STEP	ITEM NO.	FAILURE MODE	FAILURE EFFECT A - System C - Mission B - Subsystem D - Personnel	HAZARD IDENTIFIED Yes/No	PRIMARY CAUSE
2.3	Precondition and sample Propellant Module tanks	1	Module implosion during preconditioning	A Fire/explosion in cargo bay B Propellant module tank rupture C Loss of mission D Thermal/fragmentation	Yes Yes No No	Collapse of ullage pressure Rupture of Propellant Module in cargo bay caused by implosion Insufficient/loss of ullage tank pressure

Temp-S-3168

MISSION PHASE - PRELAUNCH

PROGRAM ISPLS FMEA NO. 2.4.1

REF. FFBD	OPERATIONAL STEP	ITEM NO.	FAILURE MODE	FAILURE EFFECT A - System C - Mission B - Subsystem D - Personnel	HAZARD IDENTIFIED Yes/No	PRIMARY CAUSE
2.4	Perform propellant loading (Propellant Module)	1	Failure to transfer (Slush LH_2)	A Line blockage/rupture	Yes	Ice clogging at line bends
				B Module subsystem damage	Yes	Ice damage to tank sensors
				C_1 Delay of mission	No	
				C_2 Loss of mission	Yes	Damaged baffels, subsystems by ice impact/scrubbing
				D Thermal/fragmentation	No	
		2	Tank over-pressurization	A Fire/explosion with loss of shuttle	Yes	Loss of insulation purge/ off load/vent capability
				B_1 Propellant module tank rupture	Yes	Loss of insulation purge/ off load/vent capability
				B_2 Propellant module tank rupture	Yes	Failure of pressure regulation
				C Loss of mission	Yes	Loss of shuttle orbiter
				D Thermal fragmentation	Yes	Explosion/fire occurring when crews are in area/crews in cargo/crew module, after tank rupture.

Temp-S-3168

MISSION PHASE - PRELAUNCH PROGRAM ISPLS FMEA NO. 2.4.6

REF. FFBD	OPERATIONAL STEP	ITEM NO.	FAILURE MODE	FAILURE EFFECT A - System C - Mission B - Subsystem D - Personnel	HAZARD IDENTIFIED Yes/No	PRIMARY CAUSE
2.4	Terminate propellant replenishment	1	Feedline QD fails open (major leak)	A Explosive vapor/fluid in cargo bay/fire explosion	Yes	Contamination in QD
				B Module implosion	Yes	Fluid loss without ullage makeup pressure
				C Loss/delay of mission	Yes	Cryogenic fluid stressing of cargo bay structure
				D Thermal/fragmentation	Yes	Fire/explosion
		2	Feedline QD fails to seat (minor leakage)	A Cargo bay contamination	Yes	Contamination in QD or faulty seal
				B Complicates reconnect operation	Yes	
				C Delay of mission	No	
				D_1 Hazardous Vapors	Yes	
				D_2 Thermal	Yes	

Temp-S-3168

MISSION PHASE - PRELAUNCH

PROGRAM ISPLS FMEA NO. 7.0

REF. FFBD	OPERATIONAL STEP	ITEM NO.	FAILURE MODE	FAILURE EFFECT A - System C - Mission B - Subsystem D - Personnel	HAZARD IDENTIFIED Yes/No	PRIMARY CAUSE
2.4	Perform Mission Abort operations	1	Emergency propellant offload system inoperative	A Possible system degradation	Yes	GSE power failure/power to fill and drain valves lost
				B Possible overpressurization if LH_2 slush is in-tank (propellant module)	Yes	
				C Delay/loss of mission	Yes	
				D Thermal/fragmentation	Yes	

Temp-S-3168

MISSION PHASE - LAUNCH AND ASCENT PROGRAM ISPLS FMEA NO. 2.6.1

REF. FFBD	OPERATIONAL STEP	ITEM NO.	FAILURE MODE	FAILURE EFFECT A - System C - Mission B - Subsystem D - Personnel	HAZARD IDENTIFIED Yes/No	PRIMARY CAUSE
2.6	Perform initial ascent maneuver	1	Line/bellows rupture or leakage	A Fire/explosion/structural failure	Yes	Structural failure of line or bellows
				B Renders inoperative	Yes	
				C Loss of mission	Yes	
				D Loss of crew	Yes	
		2	Orbiter vehicle propellant tank under pressurizes	A Fire/explosion in engine area	Yes	Failure of pressure regulator to ullage
				B Loss of functional integrity	Yes	
				C Loss of mission	Yes	
				D Loss of crew	Yes	
		3	Internal insulation failure	A Potential loss	Yes	Internal insulation cracks, peels, flakes clogging system
				B Potential loss	Yes	
				C Loss of mission	Yes	
				D Potential loss of crew	Yes	
		4	Helium pressure tank rupture	A Potential loss of vehicle to explosive blast	Yes	Material defect
				B_1 Potential loss of one of two subsystems	Yes	
				B_2 Loss of one engine	Yes	
				C Mission abort		
				D Loss of crew to blast, fragmentation or vehicle control capability.		
		5	Accumulator/lines rupture	A Potential loss of vehicle due to blast/fragmentation damage	Yes	Material defect
				B_1 Loss of subsystem	Yes	
				B_2 Loss of engine	Yes	
				C Mission abort	Yes	

Temp-S-3168

MISSION PHASE - ORBITAL PROGRAM ISPLS FMEA NO. 3.1

REF. FFBD	OPERATIONAL STEP	ITEM NO.	FAILURE MODE	FAILURE EFFECT A - System C - Mission B - Subsystem D - Personnel	HAZARD IDENTIFIED Yes/No	PRIMARY CAUSE
3.0	Perform Rendez-vous	1	Impact with passive target	A_1 Structural damage	Yes	Failure of approach radar, communications and human error
				A_2 System rupture/ explosion	Yes	
				B Loss of mission	Yes	
				C Loss of crew	Yes	
		2	Impact by meteroid	A Structural damage	Yes	Meteoroid penetration
				B_1 Potential loss of GNC capability	Yes	
				B_2 Possible loss of communication	Yes	
				C_1 Mission delay	No	
				C_2 Mission loss	Yes	
				D_1 Potential loss of ECLSS	Yes	
				D_2 Crew loss to explosion/ fire	Yes	
		3	Impact with space debris	A Structural damage	Yes	Failure to detect debris in flight path
				C_1 Delay of mission	No	
				C_2 Loss of mission	Yes	
				D Loss of crew	Yes	
		4	Loss of command communication	A Inability to rendezvous with passive target with transponder out	Yes	Data link failure up/down
				C_1 Mission delay	No	
				C_2 Mission loss	Yes	
				D Loss of crew	Yes	
		5	Loss of attidude	A Instability	Yes	Failure in stabilization system
				B Loss of functional control	Yes	

Temp-S-3168

MISSION PHASE - ORBITAL PROGRAM ISPLS FMEA NO. 3.1 (Cont.)

REF. FFBD	OPERATIONAL STEP	ITEM NO.	FAILURE MODE	FAILURE EFFECT A - System C - Mission B - Subsystem D - Personnel	HAZARD IDENTIFIED Yes/No	PRIMARY CAUSE
		5		C Delay/loss of mission D Possible loss of crew	No Yes	
		6	Loss of electrical power	A System rendered inoperative C Loss of mission D Loss of crew	Yes No Yes	Control system malfunction
		7	Failure of Space Radiators in intermediate position	A System efficiency reduced. B Reduced ECLSS Operation C Delay of mission D Crew discomfort	Yes Yes No No	Failure of cargo bay doors to fully open
		8	OMS Engines fail to cutoff	A Potential structural impact C Delay/loss of mission D Potential loss due to ECLSS or hull penetration	Yes Yes Yes	Delay in closing the LH_2/LOX supply pre-valves

Temp-S-3168

MISSION PHASE - ORBITAL

PROGRAM ISPLS FMEA NO. 3.2

REF. FFBD	OPERATIONAL STEP	ITEM NO.	FAILURE MODE	FAILURE EFFECT A - System C - Mission B - Subsystem D - Personnel	HAZARD IDENTIFIED Yes/No	PRIMARY CAUSE
3.0	Maneuver to emplace payload/ equipment or LO_2 module	1	Impact of vehicle	A Structural damage B Possible insulation damage C Delay of mission D Possible loss of crew compartment environment	Yes Yes No 	Improper procedure or restricted vision/aids
		2	Propulsive vent valve fails open	A Potential impact damage B Loss of propellant conditioning C Delay of mission D Possible impact (body) damage	Yes No No Yes	Contamination

Temp-S-3168

MISSION PHASE - ORBITAL PROGRAM ISPLS FMEA NO. 3.3

REF. FFBD	OPERATIONAL STEP	ITEM NO.	FAILURE MODE	FAILURE EFFECT A - System C - Mission B - Subsystem D - Personnel	HAZARD IDENTIFIED Yes/No	PRIMARY CAUSE
3.0	Deploy payload LO_2 and equipment or crew module/ dock	1	Manipulator fails in intermediate mode	A Cargo doors cannot be closed	Yes	Electrical/mechanical failure
				B Cargo suspended on manipulator	Yes	
				C_1 Delay of mission	No	
				C_2 Loss of mission	Yes	
				D Requires EVA for corrective action	Yes	
		2	Manipulator overcontrols	A_1 Disturbance imposed which causes instability	Yes	Control failure
				A_2 Possible damage to system structure	Yes	
		3	Manipulator aids	B_1 TV lost	Yes	Electro-mechanical failure
				B_2 Lighting lost	Yes	
				B_3 Control operators canopy fairing door affected	Yes	
				C Delay of mission	No	
		4	Docking ring fails to latch	A System will not seal properly	Yes	Damaged surface or contamination
				B Docking ring will not be pulled down and rigidized	Yes	
				D Delay in personnel transfer	No	
		5	Structural failure	A_1 Damage to docking ring	Yes	Undesired propulsive ΔV
				A_2 Insulation damage	Yes	
				B_1 Damage to propellant transfer connections	Yes	
				B_2 Rupture of propellant tank	Yes	

Temp-S-3168

MISSION PHASE - ORBITAL PROGRAM ISPLS FMEA NO. 3.3 (Cont.)

REF. FFBD	OPERATIONAL STEP	ITEM NO.	FAILURE MODE	FAILURE EFFECT A - System C - Mission B - Subsystem D - Personnel	HAZARD IDENTIFIED Yes/No	PRIMARY CAUSE
		5		C Propellants not available mission requirements	No	
				D Loss of ECLSS effectiveness through leaking seal at hatchway	Yes	
		6	Cargo doors fail to open	A System degraded	No	Loss of power
				B Rendered inoperative	No	
				C Delay of mission		
		7	Loss of communication	A Impair the system	No	Electrical/electronic failure
				B Functional capability lost	No	
				C Delay of mission	No	
				D Crew exposed to communication blockout	Yes	
		8	Docking Adaptor Latch releases suddenly under load	B Loss of function	No	Undocking after misalignment
				C Delay of mission	No	
				D Subjected to disturbances	Yes	
		9	Passive vehicle goes unstable	A Impact	Yes	Erroneous command of control function/ground communication net
				C Delay of mission	No	

Temp-S-3168

MISSION PHASE - ORBITAL

PROGRAM ISPLS FMEA NO. 3.4

REF. FFBD	OPERATIONAL STEP	ITEM NO.	FAILURE MODE	FAILURE EFFECT A - System C - Mission B - Subsystem D - Personnel	HAZARD IDENTIFIED Yes/No	PRIMARY CAUSE
3.0	Activate selected subsystems (CIS/ RNS Supportive S-II Derivative Buildup)	1	Fails to activate	A Renders the system inoperative	No	Loss of remote activation capability from ground net or Shuttle
				B Inactive subsystem/ fails to operate	No	
				C Delay of Mission	No	
				D EVA required for repair/ maintenance	Yes	
		2	Airlock Seal leaking	A Reduces capability to maintain environment in crew station	Yes	Hard dock
				B Creates rapid expenditure of ECLSS fluids	Yes	
				C Delay of mission	No	
				D Personnel required to wear space suits or portable life support suits	Yes	
		3	Equipment Module/ Crew Module ECLSS fails to provide habitable environment	A Renders inoperative	Yes	Electro/mechanical failure
				B Crew compartments shirtsleeve environment lost	Yes	
				C Delay of mission	No	
				D_2 May require use of space suits	Yes	

Temp-S-3168

MISSION PHASE - ORBITAL

PROGRAM ISPLS FMEA NO. 3.5

REF. FFBD	OPERATIONAL STEP	ITEM NO.	FAILURE MODE	FAILURE EFFECT A - System C - Mission B - Subsystem D - Personnel	HAZARD IDENTIFIED Yes/No	PRIMARY CAUSE
3.0	Perform final checkout of subsystems	1	Gas leakage in equipment module or tunnel area.	A_1 Possible contamination of environment in habitable areas	Yes	Line connection seal damaged
				A_2 Possible damage to access-line inter-connect system	Yes	
				B Overloading of ECLSS	Yes	
				D Environment contamination would require use of space suits	Yes	
		2	Inability to start fuel cells	A Delays accomplishment of buildup and checkout operations	No	
				B Renders subsystem inoperative after battery power is expended	No	
				C Delays mission	No	
				D Space suits or portable life support suits would be required for personnel	No	
		3	Shorting of electrical connectors at interface	A Electrical overload	Yes	Lines mismatched/grounded
				B Welded contacts	Yes	
				B_1 Potential fire/ contamination	Yes	
				C Loss of mission	No	

Temp-S-3168

MISSION PHASE - ORBITAL PROGRAM ISPLS FMEA NO. 3.6

REF. FFBD	OPERATIONAL STEP	ITEM NO.	FAILURE MODE	FAILURE EFFECT A - System C - Mission B - Subsystem D - Personnel	HAZARD IDENTIFIED Yes/No	PRIMARY CAUSE
3.0	Uncouple/undock from payload	1	Manipulator fails to release	B Renders inoperative	Yes	Electro/mechanical failure
				C Delay of mission	No	
				D_1 Requires EVA for repairs	Yes	
				D_2 Requires implementation of contingency means	No	
		2	Manipulator binds with sudden release	A_1 Undesired disturbances in Shuttle	Yes	Mechanical
				A Structural damage to module	Yes	
				B_1 Oscillating perturbations in the manipulator subsystem	Yes	
				C Delay of mission	No	
				D Subjected to disturbances	Yes	
		3	Docking adapter ruptures	A Loss of function	No	Fatigue stress concentrations
				B Loss of subsystem	No	
				C Loss of mission	No	
				D Possible decompression of habitable areas	Yes	

Temp-S-3168

MISSION PHASE - ORBITAL PROGRAM ISPLS FMEA NO. 3.7

REF. FFBD	OPERATIONAL STEP	ITEM NO.	FAILURE MODE	FAILURE EFFECT A - System C - Mission B - Subsystem D - Personnel	HAZARD IDENTIFIED Yes/No	PRIMARY CAUSE
3.0	Separate to safe distance from buildup operation	1	Inability to translate as required	A Possible impact damage	Yes	Failure to ignite/intermittent burning of RCS
				C Delay of mission	No	
				D Possible loss of ECLSS by impact	Yes	
		2	Erroneous control maneuver commanded	A Impact damage	Yes	Human error/disorientation
				C_1 Delay of mission	No	
				C_2 Loss of mission	Yes	
				D Possible loss of crew	Yes	
		3	Failure to stabilize	A Possible impact	Yes	Human error/intermittent operation of RCS/venting at propulsive vents
				C Delay/loss of mission	Yes	
				D Possible loss of habitable environment by impact	Yes	

Temp-S-3168

MISSION PHASE - ORBITAL

PROGRAM ISPLS FMEA NO. 4.2

REF. FFBD	OPERATIONAL STEP	ITEM NO.	FAILURE MODE	FAILURE EFFECT A - System C - Mission B - Subsystem D - Personnel	HAZARD IDENTIFIED Yes/No	PRIMARY CAUSE
4.0	Rendezvous with other orbiting body	1 thru 8	Same as Operational Step 3.1			

Temp-S-3168

MISSION PHASE - ORBITAL

PROGRAM ISPLS FMEA NO. 4.2

REF. FFBD	OPERATIONAL STEP	ITEM NO.	FAILURE MODE	FAILURE EFFECT A - System C - Mission B - Subsystem D - Personnel	HAZARD IDENTIFIED Yes/No	PRIMARY CAUSE
4.0	Deploy propell-and module	1	Manipulator fails in intermediate mode	A Cargo doors cannot be closed	Yes	Power/mechanical failure
				B Cargo suspended on manipulator	Yes	
				C Delay of mission	No	
				D Requires possible EVA for corrective action	Yes	
		2	Manipulators overcontrols	A_1 Disturbances imposed which causes instability	Yes	Control failure
				A_2 Possible damage to system structure	Yes	
		3	Manipulator aids fail to function	B_1 TV presentation lost	Yes	Electro-mechanical failure
				B_2 Lighting lost	Yes	
				B_3 Prevents control operators canopy fairing door from opening	Yes	
		4	Shift in CG	A Impact/fragmentation damage	Yes	Transpositioning of propellant module
				C Delay of mission	No	
				D Possible fragmentation damage	Yes	

Temp-S-3168

MISSION PHASE - ORBITAL PROGRAM ISPLS FMEA NO. 4.4

REF. FFBD	OPERATIONAL STEP	ITEM NO.	FAILURE MODE	FAILURE EFFECT A - System C - Mission B - Subsystem D - Personnel	HAZARD IDENTIFIED Yes/No	PRIMARY CAUSE
4.0	Dock with orbiting body	1	Docking ring fails to latch	A System will not seal properly	Yes	Damaged surface or Contamination
				B Docking ring will not be pulled down and rigidized	Yes	
		2	Docking adapter latch releases suddenly under load	B_1 Loss of function	No	Undocking after misalignment
				C Delay of mission	No	
				D Subjected to disturbances	Yes	
		3	Passive vehicle goes unstable	A Impact	Yes	Erroneous command of control function/ground communication net
				C Delay of mission	No	
		4	Functional docking aids obscured or failed	A Docking impact	Yes	Loss of TV, contamination or target illumination
				C Delay of mission	No	
				D Possible loss of crew	Yes	
		5	Manipulator fails to emplace docking adapter	C Mission delay	No	Electro-mechanical
		6	Manipulator fails to effect docking operation	A System functional degradation	No	Electro-mechanical
				B Inoperative or marginal operation	No	
				C Delay of mission	No	

Temp-S-3168

MISSION PHASE - ORBITAL

PROGRAM ISPLS FMEA NO. 4.5

REF. FFBD	OPERATIONAL STEP	ITEM NO.	FAILURE MODE	FAILURE EFFECT A - System C - Mission B - Subsystem D - Personnel	HAZARD IDENTIFIED Yes/No	PRIMARY CAUSE
4.0	Transfer/unload propellants	1	Failure of line interconnect fixture indexing probes to rigidize fixture	A Renders system inoperative	Yes	Meteoroid shield not retracted/failure of drive mechanism
				B Damage to probes	Yes	
				C Mission delay	No	
		2	Failure of line extension bellows	A_1 Fire/explosion (if confined)	Yes	Mechanical failure
				A_2 Ice crystal cloud formation		
				B Renders subsystem inoperative		
				C Mission delay		
				D Thermal/fragmentation		
		3	Failure of QD to seal	B Leakage at QD	Yes	Contamination/defective seal
		4	Failure of automatically operated electrical connectors to extend	A Renders system inoperative	No	Loss of power/indexing probes misaligned
				C Mission delay	No	
		5	Failure of shutoff valve in closed position	A Propellant will not transfer	No	Failure of shutoff valve solenoid
		6	Structural failure	A Loss of system	Yes	Excessive loads during spin up/vehicle and propellant dynamic interaction
				C Loss of mission	Yes	
				D Loss of personnel	Yes	
		7	Flowmeter fails	A_1 Loss of quantity transfer	Yes	Electro-mechanical failure
				A_2 Loss of CG location	Yes	
				B Flow restriction	No	

Temp-S-3168

REF. FFBD	OPERATIONAL STEP	ITEM NO.	FAILURE MODE	FAILURE EFFECT A - System C - Mission B - Subsystem D - Personnel	HAZARD IDENTIFIED Yes/No	PRIMARY CAUSE
		8	LO_2 regulator to GAS generator fails in open mode	B Excessive temperature in heat exchanger	Yes	Electro-mechanical failure
				C Requires unscheduled shutdown operations	No	
		9	Gas Generator operates erratic	A System becomes inoperative	No	Low pump head pressure
				B_1 Loss of pressurant	No	
				B_2 Pump cavitation	Yes	
		10	Heat Exchanger fails	A System Contamination	Yes	Gas Generator control failure
				B Functional degradation	Yes	
				C Delay of mission	No	
		11	Source Tank outlet uncovered	A Renders unstable	Yes	Dynamic interaction of vehicle and propellant
				B_1 Possible pump cavitation	Yes	
				B_2 Possible slug flow	Yes	
				C Possible loss of mission	Yes	
				D Subjected to disturbances	Yes	
		12	Distortion of propellant fluid surface	A Causes instability/structural failure	Yes	Propellant inlet fluid momentum
				C Loss of mission	Yes	

Temp-S-3168

MISSION PHASE - ORBITAL

PROGRAM ISPLS FMEA NO. 4.6

REF. FFBD	OPERATIONAL STEP	ITEM NO.	FAILURE MODE	FAILURE EFFECT A - System C - Mission B - Subsystem D - Personnel	HAZARD IDENTIFIED Yes/No	PRIMARY CAUSE
4.0	Retrieve empty down-propellant module	1	Module docking latch fails to unlock	A Disturbance in shuttle	No	Failure of release mechanism
				B Separation hangups	No	
				C Delay of mission	No	
		2	Module undocking with line interconnect fixture still attached	A Renders interface inoperative	Yes	Improper procedures/ failed indexing fixture
				B Potential loss of propellants	Yes	
				C Mission delay	No	
		3	Manipulator fails to latch ~~out~~ on the module	A Prevents normal undocking of module	No	Electro-mechanical failure
		4	Pressurization line in interconnect fixture QD fails open after module release	A_1 Structural damage	Yes	Contamination/defective seals
				A_2 Propulsive disturbance	Yes	
				B Loading of manipulator arm	Yes	

Temp-S-3168

MISSION PHASE - ORBITAL PROGRAM ISPLS FMEA NO. 5.2

REF. FFBD	OPERATIONAL STEP	ITEM NO.	FAILURE MODE	FAILURE EFFECT A - System C - Mission B - Subsystem D - Personnel	HAZARD IDENTIFIED Yes/No	PRIMARY CAUSE
5.2	Rendezvous with Space Station/ tug/equipment, propellant or support modules	1	Failure of data link system	A Orbiter unable to rendezvous with passive target	Yes	Ground data link failure
				B Improper operation of communications system	Yes	
				C Delay in propellant delivery	No	
				D Delay in crew return to earth	Yes	
		2	Malfunction of on-board computer	A Orbiter unable to rendezvous with passive target	Yes	Electro/electronics failure
				B Improper RCS input	Yes	
				C Delay of mission		
				D Delay of crew return to earth	Yes	
		3	Malfunction of Shuttle Orbiter RCS	A Orbiter unable to terminate ΔV maneuvers	Yes	Electro/mechanical
				B Possible intermittent operation	Yes	
				C Mission delay	No	
				D Delay in crew return to earth	Yes	
		4	OMS Engine fails to cut-off	A Potential structural impact	Yes	Failure of the thrust chamber feed valve to close
				C Delay/loss of mission	Yes	
				D Potential loss of ECLSS to hull penetration	Yes	
		5	Impact with passive target	A_1 Structural damage	Yes	Failure of approach radar, communications and human error
				A_2 System rupture/explosion	Yes	
				C Loss of mission	Yes	
				D Loss of crew	Yes	

Temp-S-3168

REF. FFBD	OPERATIONAL STEP	ITEM NO.	FAILURE MODE	FAILURE EFFECT A - System C - Mission B - Subsystem D - Personnel	HAZARD IDENTIFIED Yes/No	PRIMARY CAUSE
		6	Impact by meteoroid	A Structural damage B_1 Potential loss of GNC capability B_2 Possible loss of communications C_1 Mission delay C_2 Mission loss D_1 Potential loss of ECLSS D_2 Crew loss to explosion/fire	Yes Yes Yes No Yes Yes Yes	Meteoroid penetration
		7	Impact by space debris	A Structural damage C_1 Delay of mission C_2 Loss of mission D Loss of crew	Yes Yes Yes Yes	Failure to detect debris in flight path

Temp-S-3168

MISSION PHASE - ORBITAL   PROGRAM ISPLS   FMEA NO. 5.3

REF. FFBD	OPERATIONAL STEP	ITEM NO.	FAILURE MODE	FAILURE EFFECT A - System C - Mission B - Subsystem D - Personnel	HAZARD IDENTIFIED Yes/No	PRIMARY CAUSE
5.0	Dock	1	Functional docking aids obscured or failed	A Docking impact	Yes	Contamination/loss of target illumination or functional control
				C Delay of mission	Yes	
				D Possible loss of crew	Yes	
		2	Manipulator fails to emplace docking adapter	C Mission delay	No	Electro-mechanical
		3	Vehicle fails to stabilize	A Impact	Yes	Loss of control function/ operation of propulsive vent
				C Delay of mission	No	
		4	Docking adapter will not latch	B Loss of function	No	Failure of drive chain
				C Delay of mission	No	
				D Subjected to disturbance	Yes	
		5	Manipulator fails to effect docking operations	A System functional degradation	No	Electro-mechanical
				B Inoperative or marginal operation	No	
				C Delay of mission	No	
		6	Docking ring fails to latch	A Systems will not seal property	Yes	Mechanical
				B Docking ring will not be pulled down and rigidized	Yes	
				C Mission delay	No	
				D Requires IVA in PLSS	Yes	

Temp-S-3168

REF. FFBD	OPERATIONAL STEP	ITEM NO.	FAILURE MODE	FAILURE EFFECT A - System C - Mission B - Subsystem D - Personnel	HAZARD IDENTIFIED Yes/No	PRIMARY CAUSE
5.0	Unload maintenance crew and conduct minor maintenance operations	1	Hatch fails to release	C Delay of mission	No	Mechanical
		2	Hatch valve releases prematurely	B Possible damage to hatch C Delay of mission D Possible loss of crew	No No Yes	Mechanical
		3	Hatch inoperative due to impact	B Damage to sealing surface	Yes	Impact during transfer of cargo
		4	Improper procedure during pressurization system repair	A Possible impact damage B Possible damage C Delay of mission D Possible loss of crew(s)	Yes Yes No Yes	Failure to relieve pressure prior to breaking system
		5	Failure to remove electrical power from systems prior to repair/maintenance	A Potential damage to systems B Possible loss of subsystem D Possible injury of crew member	Yes Yes Yes	Improper procedures
		6	Improper Operation of system (propellant)	A Possible damage B Possible failure D Possible injury	Yes No Yes	Procedural
		7	Maintenance installation incorrect (lines)	A Possible damage B Potential failure D Possible injury	Yes Yes	Procedural

Temp-S-3168

MISSION PHASE - ORBITAL PROGRAM ISPLS FMEA NO. 5.4 (Cont.)

REF. FFBD	OPERATIONAL STEP	ITEM NO.	FAILURE MODE	FAILURE EFFECT A - System C - Mission B - Subsystem D - Personnel	HAZARD IDENTIFIED Yes/No	PRIMARY CAUSE
		8	Communication failure	A Impairs the system	No	Electrical/electronics
				B Loss of functional capability	Yes	
				C Delay of mission	No	
				D Exposes crew to communication blackout	Yes	
		9	Propellant system contaminated	A Requires purging of system	No	Introduction of contamination during maintenance
				B Loss or reduced operational capability	Yes	
				C Delay of mission	No	
				D Possible loss of ECLSS	Yes	
		10	Failure to purge or improperly purged system	A Contamination	Yes	Procedural
				B Possible loss of capability	Yes	
				D May affect ECLSS	Yes	

Temp-S-3168

MISSION PHASE - ORBITAL PROGRAM ISPLS FMEA NO. 5.5

REF. FFBD	OPERATIONAL STEP	ITEM NO.	FAILURE MODE	FAILURE EFFECT A - System C - Mission B - Subsystem D - Personnel	HAZARD IDENTIFIED Yes/No	PRIMARY CAUSE
5.0	Dock Equipment & crews module for major maintenance	1	Hard dock fails structure/seals	A Loss C Mission delay D Possible loss of personnel	Yes Yes Yes	Failure within RCS/Avionics
		2	Docking rings fail to latch	B Delay in systems hookup D Delay in personnel transfer operations	No No	Mechanical
		3	Loss of communication	A Impairs the system B Functional capability lost C Delay of Mission D Crew exposed to communication blackout	Yes Yes No Yes	Electrical/electronics
		4	Manipulator fails in intermediate mode	A Cargo bay doors cannot be closed B Cargo suspended on manipulator C_1 Delay of mission C_2 Loss of mission D Possible EVA for corrective action	Yes Yes No Yes Yes	Electrical/mechanical failure
		5	Manipulator over-controls	A_1 Disturbance imposed which causes instability A_2 Possible damage to system structure	Yes Yes	Control failure
		6	Manipulator aids fail to function	B_1 TV lost B_2 Lighting lost B_3 Control operators canopy fairing door cannot open	Yes Yes	Electro/mechanical failure

Temp-S-3168

MISSION PHASE - ORBITAL PROGRAM ISPLS FMEA NO. 5.5 (Cont.)

REF. FFBD	OPERATIONAL STEP	ITEM NO.	FAILURE MODE	FAILURE EFFECT A - System C - Mission B - Subsystem D - Personnel	HAZARD IDENTIFIED Yes/No	PRIMARY CAUSE
		7	Cargo doors fail to open	A System degraded B Rendered inoperative C Delay of mission	No No No	Loss of power

Temp-S-3168

MISSION PHASE - ORBITAL

PROGRAM ISPLS FMEA NO. 5.6

REF. FFBD	OPERATIONAL STEP	ITEM NO.	FAILURE MODE	FAILURE EFFECT A - System C - Mission B - Subsystem D - Personnel	HAZARD IDENTIFIED Yes/No	PRIMARY CAUSE
5.0	Undock	1	Manipulator fails to release	B Renders inoperative	Yes	Electro/mechanical failure
				C Delay of mission	No	
				D_1 Possible EVA for repairs	Yes	
				D_2 Requires implementation of contingency means	No	
		2	Manipulator binds with sudden release	A_1 Undesired disturbances in shuttle	Yes	Electro/mechanical
				A_2 Structural damage to module	Yes	
				B Oscillating perturbations in the manipulator subsystem	Yes	
				C Delay of mission	No	
				D Subjected to disturbances	Yes	
		3	Docking adapter ruptures	A Loss of function	Yes	Fatigue stress concentration
				B Loss of subsystem	Yes	
				C Loss of mission	Yes	
				D Possible decompression of habitable areas	Yes	

Temp-S-3168

MISSION PHASE - ORBITAL PROGRAM ISPLS FMEA NO. 5.7

REF. FFBD	OPERATIONAL STEP	ITEM NO.	FAILURE MODE	FAILURE EFFECT A - System C - Mission B - Subsystem D - Personnel	HAZARD IDENTIFIED Yes/No	PRIMARY CAUSE
5.0	Separate to safe distance for stay	1	Failure to stabilize	A Possible impact	Yes	Human error/intermittent operation of RCS/venting or propulsive vents
				C Delay/loss of mission	Yes	
				D Possible loss of habitable environment by impact	Yes	
		2	Inability to translate as required	A Possible impact damage	Yes	Failure to ignite/intermittence burning of RCS
				C Delay of mission	No	
				D Possible loss of ECLSS by impact	Yes	
		3	Erroneous control maneuver commanded	A Impact damage	Yes	Human error/fatigue/disorientation
				C_1 Delay of mission	No	
				C_2 Loss of mission	Yes	
				D Possible loss of crew	Yes	

Temp-S-3168

MISSION PHASE - ORBITAL PROGRAM ISPLS FMEA NO. 5.9

REF. FFBD	OPERATIONAL STEP	ITEM NO.	FAILURE MODE	FAILURE EFFECT A - System C - Mission B - Subsystem D - Personnel	HAZARD IDENTIFIED Yes/No	PRIMARY CAUSE
5.0	Redock	1	Docking ring fails to latch	A System will not seal property	Yes	Damaged surface or contamination
				B Docking ring not pulled down and rigidized	Yes	
		2	Docking adaptor latch will not operate	B_1 Loss of function	Yes	Drive chain break
				C Delay of mission	Yes	
				D Subjected to disturbances	Yes	
		3	Failure of passive vehicle to stabilize	A Impact	Yes	Loss of control function/ ground communications net
				C Delay of mission	No	
		4	Functional docking aids obscured or failed	A Docking impact	Yes	Loss of TV, contamination or target illumination
				C Delay of mission	No	
				D Possible loss of crew	Yes	
		5	Manipulator fails to implace docking adapter	C Mission delay	No	Electro-mechanical
		6	Manipulator fails to effect docking operation	A Systems functional degradation	No	Electro-mechanical
				B Inoperative or marginal operation	No	
				C Delay of mission	No	

Temp-S-3168

MISSION PHASE - ORBITAL PROGRAM ISPLS FMEA NO. 5.10

REF. FFBD	OPERATIONAL STEP	ITEM NO.	FAILURE MODE	FAILURE EFFECT A - System C - Mission B - Subsystem D - Personnel	HAZARD IDENTIFIED Yes/No	PRIMARY CAUSE
5.0	Transfer down	1	Manipulator fails with excessive deployment rate	A Potential impact damage B Control degradation C Delay/loss of mission D Loss of habitable environment	Yes Yes Yes Yes	Electro-mechanical
		2	Manipulator fractures overstressed	A Uncontrolled disturbances B System function impaired C Mission delay D Possible loss of ECLSS	Yes Yes Yes Yes	Mechanical/material
		4	Manipulator aid fails "off"	A Reduces functional capability B Degradation of function C Delay of mission D Possible loss of ECLSS	Yes Yes No Yes	Electrical/mechanical failure
		5	Module QD fitting fails to seal	A Contamination of module C Delay of mission D Contaminated environment	Yes No Yes	Mechanical/contamination

Temp-S-3168

MISSION PHASE - ORBITAL

PROGRAM ISPLS FMEA NO. 5.11

REF. FFBD	OPERATIONAL STEP	ITEM NO.	FAILURE MODE	FAILURE EFFECT A - System C - Mission B - Subsystem D - Personnel	HAZARD IDENTIFIED Yes/No	PRIMARY CAUSE
5.0	Load Maintenance crew and minor cargo	1	Airlock doors fail to seal pressure volume (crew module) (equipment module)	D Requires use of portable life support suit	Yes	Procedural or mechanical failure

Temp-S-3168

MISSION PHASE - ORBITAL PROGRAM ISPLS FMEA NO. 6.1

REF. FFBD	OPERATIONAL STEP	ITEM NO.	FAILURE MODE	FAILURE EFFECT A - System C - Mission B - Subsystem D - Personnel	HAZARD IDENTIFIED Yes/No	PRIMARY CAUSE
6	Retract module into cargo bay	1	Manipulator fails with excessive deployment rate	A Potential impact damage B Control degradation C Delay/loss of mission D Loss of habitable (shirt sleeve) environment	Yes Yes Yes Yes	Electro-mechanical
		2	Manipulator fails to retract	B Degradation of function C Mission delay	Yes Yes	Loss of control function
		3	Manipulator fractures bends or fails to stop	A Uncontrolled disturbances B System functional impaired C Mission delay D Loss of ECLSS	Yes Yes Yes Yes	Mechanical/material
		4	Manipulator Aids fail "off"	A Reduces functional capability B Degradation of function C Delay of mission D Loss of ECLSS	Yes Yes No Yes	Electrical/mechanical failure

Temp-S-3168

MISSION PHASE - ORBITAL PROGRAM ISPLS FMEA NO. 6.2

REF. FFBD	OPERATIONAL STEP	ITEM NO.	FAILURE MODE	FAILURE EFFECT A - System C - Mission B - Subsystem D - Personnel	HAZARD IDENTIFIED Yes/No	PRIMARY CAUSE
6.0	Secure Module	1	Fails to latch at forward attach fitting	A Cargo bay, cargo bay doors and module would be structurally damaged	Yes	Operational/mechanical
				B Axial, vehicle and side loads could not be taken	Yes	
				C Delay of mission	No	
				D Delays transfer IVA to orbiter	Yes	
		2	Fails to attack at aft fitting	A Possible structural damage	Yes	Operational/mechanical
				B Vertical loads cannot be taken	Yes	
				C Loss of mission	Yes	
				D Partial loss of ECLSS	Yes	
		3	Internal propellant tank module pressure low	A Possible tank implosion in venting	Yes	Electro-mechanical failure
				B Inability to make-up pressure	Yes	
				C Loss of mission	Yes	
				D Possible loss of crew	Yes	
		4	Propellant module vent system fails to connect to vent lines	A Possible venting in bay	Yes	Improper procedure/mechanical failure
				B Potential fire/explosion	Yes	
				C Loss of mission	Yes	
				D Possible loss of crew		
		5	Retractable tunnel fails to seal with crew module access port	A System degradation	Yes	Failure of retractable tunnel element/or module misalignment
				B Inability to transfer crew IVA	Yes	
				C Delay of mission	No	
				D Requires EVA to shuttle	No	

Temp-S-3168

MISSION PHASE – ORBITAL PROGRAM ISPLS FMEA NO. 6.2 (Cont.)

REF. FFBD	OPERATIONAL STEP	ITEM NO.	FAILURE MODE	FAILURE EFFECT A - System C - Mission B - Subsystem D - Personnel		HAZARD IDENTIFIED Yes/No	PRIMARY CAUSE
		6	Pressure hatch fails in "locked" position	B	Inability to transfer crew IVA	No	Mechanical failure
				D	Requires EVA to enter shuttle	No	
		7	Communication failure	B	Inability to conduct operations	Yes	Electrical/electronic failure
				C	Delay of mission	No	
				D	Requires alternate communication mode	Yes	
		8	Venting during vent hookup	D	Exposure to cryogenic temperatures	Yes	Improper procedure

Temp-S-3168

MISSION PHASE - ORBITAL

PROGRAM ISPLS FMEA NO. 3.1A

REF. FFBD	OPERATIONAL STEP	ITEM NO.	FAILURE MODE	FAILURE EFFECT A - System C - Mission B - Subsystem D - Personnel		HAZARD IDENTIFIED Yes/No	PRIMARY CAUSE
3.0A	Configure Shuttle Orbiter for Payload deployment operation	1	Cargo bay doors fail closed	C	Abortive mission	No	Electro-mechanical
		2	Manipulators fail to function	C	Abortive mission	No	Control system failure
		3	Manipulator impacts vehicle in cargo bay	A	Possible tank rupture	Yes	Manipulator driven into vehicle during operation
				C	Mission loss for Tug	No	
				D	Possible injury (where crew module attached in tug)	Yes	
		4	Propellant transfer line fails	B	Renders propellant loading impossible	Yes	Mechanical stressing
				C	Delay of mission	No	
				D	Possible injury/loss	Yes	

Temp-S-3168

MISSION PHASE - ORBITAL

PROGRAM ISPLS FMEA NO. 3.2A

REF. FFBD	OPERATIONAL STEP	ITEM NO.	FAILURE MODE	FAILURE EFFECT A - System C - Mission B - Subsystem D - Personnel	HAZARD IDENTIFIED Yes/No	PRIMARY CAUSE
3.0A	Transfer Propellants to Delivery Vehicle (Tug)	1	Three way propellant transfer valve fails to vent	B Buildup of pressure trapped between transfer valve and OMS propellant loading valve	Yes	Valve positioned wrong
		2	Low head to the transfer pump inlet	A Extends time to transfer propellants	No	Orientation of fluids in OMS tanks
				B_1 Pump cavitation	Yes	
				B_2 Lost control of fluid transferred	Yes	
		3	Fill and drain disconnect fails during transfer of propellants	A Cargo bay subjected to fluid leakage	Yes	Improper installation
				B Reduces transfer capability	Yes	
				C Delay of mission	No	
				D Subjected to potential explosion (Orbiter)	Yes	
		4	Fill and drain valve fails closed	A System inoperative	No	Electro-mechanical failure
				B Prevents propellant transfer	No	
				C Delay mission	No	
		5	LO_2 tank vent fails open (Centaur)	A Reduced engine performance	No	Implosion of common bulkhead
				B_1 Loss of tank pressurization in Tug	No	
				B_2 Loss of LO_2 tank pressure Centaur	Yes	
				C Loss of mission	No	
		6	Auxillary transfer pump fails explosively	A Cargo bay subjected to cryogens	No	Auxillary transfer pump rubbing internally
				B Potential explosion	Yes	
				C Potential loss of delivery vehicle	Yes	
				D Potential loss of Orbiter crew	Yes	

Temp-S-3168

MISSION PHASE - ORBITAL PROGRAM ISPLS FMEA NO. 3.3A

REF. FFBD	OPERATIONAL STEP	ITEM NO.	FAILURE MODE	FAILURE EFFECT A - System C - Mission B - Subsystem D - Personnel	HAZARD IDENTIFIED Yes/No	PRIMARY CAUSE
3.0A	Transfer down module to orbiter cargo bay	1	Docked module fails to detach from Tug	C Mission delay	No	Mechanical failure
		2	Manipulator fails during transfer operation	A Potential structural damage	Yes	Mechanical failure
				B Unable to emplace the payload	No	
				C Mission loss	Yes	
	Space based Tug	3	Tug becomes unstable	A Possible impact	Yes	Improper operational technique/control failure
				C Delay/loss of mission	Yes	
				D Impact on pressure hull/loss of ECLSS (Crew module attached)	Yes	
		4	Module fails to latch to cargo bay attach fittings	A Possible structural damage	Yes	Configuration differences. Human error
				B Reduces loading capability	Yes	
				C_1 Delay of mission	No	
				C_2 Loss of mission	Yes	
				D Potential injury from explosion	Yes	
		5	Module not pressurized	A Implosion upon reentry	Yes	Loss of module pressure
				C Loss of mission	Yes	
				D Subjected to cargo bay area fire/explosion	Yes	

Temp-S-3168

MISSION PHASE - ORBITAL PROGRAM ISPLS FMEA NO. 3.4A

REF. FFBD	OPERATIONAL STEP	ITEM NO.	FAILURE MODE	FAILURE EFFECT A - System C - Mission B - Subsystem D - Personnel	HAZARD IDENTIFIED Yes/No	PRIMARY CAUSE
3.0A	Transfer delivery vehicle down for maintenance	1	Stabilization fails during rendezvous	A Unable to effect capture by Orbiter (Centaur) C Delay of mission D Possible injury of crew (Tug with attached crew module)	No No Yes	Loss of system control
		2	Manipulator fails to "lock on"	B Loss of operation C Delay of mission	No No	Mechanical failure
		3	Manipulator fails to effect proper placement in cargo bay	A Possible structural damage C_1 Delay of mission C_2 Loss of mission D Possible loss of crew, (crew module attached, Tug)	Yes No Yes Yes	Mechanical/procedural
		4	Vehicle fails to latch at attach points	A Possible loss of system B Damage to cargo bay C Loss of mission D Possible loss of crew (Orbiter)	Yes Yes Yes Yes	Mechanical/configuration

Temp-S-3168

MISSION PHASE - ORBITAL PROGRAM ISPLS FMEA NO. 3.6A

REF. FFBD	OPERATIONAL STEP	ITEM NO.	FAILURE MODE	FAILURE EFFECT A - System C - Mission B - Subsystem D - Personnel	HAZARD IDENTIFIED Yes/No	PRIMARY CAUSE
3.0A	Deploy delivery vehicle (PPS-1 thru 7)	1	Releases from all attach fittings except one	A May introduce stress in structure C Delay of mission D May require EVA	Yes No Yes	Failure of mechanical latch system
	PPS-1 FW-4S Deriv. 2 Agena 3 Agena Deriv 4 Centaur 5 Centaur Deriv 6 Ground based Tug (OOS) 7 Space based Tug	2	Manipulator action erratic	A Possible impact B Potential cocking in cargo bay C Delay of mission	Yes Yes No	Mechanical/operator
		3	Manipulator aids fail	A Reduces operational integrity B Renders inoperative C Delay of mission	Yes Yes No	Electro/mechanical
		4	Orbiter RCS activates when vehicle is partially out of the cargo bay	A Load becomes unstable B Flexing of manipulator C Delay of mission	Yes Yes No	Stabilization Control System
		5	QD fails to release (Tug/Centaur)	A Cargo bay slugged with cryogenic fluid B Loss of propellant/ payload C Delay of mission	Yes Yes No	Mechanical

Temp-S-3168

MISSION PHASE - ORBITAL PROGRAM ISPLS FMEA NO. 3.7A

REF. FFBD	OPERATIONAL STEP	ITEM NO.	FAILURE MODE	FAILURE EFFECT A - System C - Mission B - Subsystem D - Personnel	HAZARD IDENTIFIED Yes/No	PRIMARY CAUSE
3.0A	Separate from delivery vehicle	1	Unprogrammed Orbiter movement	A Possible impact	Yes	Stabilization system/ human error
				B RCS fires intermittently	Yes	
				D Possible injury from impact		

Temp-S-3168

MISSION PHASE - ORBITAL PROGRAM ISPLS FMEA NO. 3.8A

REF. FFBD	OPERATIONAL STEP	ITEM NO.	FAILURE MODE	FAILURE EFFECT A - System C - Mission B - Subsystem D - Personnel	HAZARD IDENTIFIED Yes/No	PRIMARY CAUSE
3.0A	Deploy payload module Propellant/Module PPS-7	1	Releases from all attach fittings except one	A May introduce stress in structure C Delay of mission D May require EVA	Yes No Yes	Failure of mechanical latch system
	PPS-7 Space based Tug	2	Manipulator action erratic	A Possible impact B Potential cocking in cargo bay C Delay of mission	Yes Yes No	Mechanical/operator
		3	Manipulator aids fail	A Reduces operational integrity B Renders inoperative C Delay of mission	Yes Yes No	Electro-mechanical
		4	Orbiter RCS activates when vehicle is partially out of the cargo bay	A Load becomes unstable B Flexing of manipulator C Delay of mission	Yes Yes	Stabilization Control System

Temp-S-3168

REF. FFBD	OPERATIONAL STEP	ITEM NO.	FAILURE MODE	FAILURE EFFECT A - System C - Mission B - Subsystem D - Personnel	HAZARD IDENTIFIED Yes/No	PRIMARY CAUSE
3.0A	Dock payload module to delivery vehicle (PPS-7)	1	Fails to stabilize	A Payload in disturbed condition	Yes	Improper operation of stabilizing controls/ propulsive vent operation
				B Manipulators will flex	Tes	
				C Delay of mission	No	
		2	Manipulators aids fail	A Docking effectiveness reduced	Yes	Electro/mechanical
				B Potential impact damage	Yes	
				C Mission delay	No	
	PPS-7 Space based Tug	3	Latch hangup after abortive docking attempt	D Possible disturbance	Yes	Incorrect procedure
		4	Communication system failure	A Inability to coordinate manipulator movement with crew (Tug and crew module attached)	Yes	Electro/mechanical
				C Delay of mission	No	
				D Potential injury from impact	Yes	
		5	Overcontrol	A Impact	Yes	Improper RCS operation
				C Mission delay	No	
				D Potential injury from impact (Orbiter crew)	Yes	

Temp-S-3168

MISSION PHASE - ORBITAL PROGRAM ISPLS FMEA NO. 3.10A

REF. FFBD	OPERATIONAL STEP	ITEM NO.	FAILURE MODE	FAILURE EFFECT A - System C - Mission B - Subsystem D - Personnel	HAZARD IDENTIFIED Yes/No	PRIMARY CAUSE
3.0A	Separate from delivery vehicle (Orbiter)	1	Unprogrammed Orbiter movement	A Possible impact B RCS fires intermittently D Possible injury from impact	Yes Yes	Stabilization system/ human error

Temp-S-3168

MISSION PHASE - ORBITAL PROGRAM ISPLS FMEA NO. 4.2A

REF. FFBD	OPERATIONAL STEP	ITEM NO.	FAILURE MODE	FAILURE EFFECT A - System C - Mission B - Subsystem D - Personnel	HAZARD IDENTIFIED Yes/No	PRIMARY CAUSE
4.0A	Rendezvous with LSF (PPS-7)	1	Impact with LSF	A Structural damage	Yes	Failure of G&C, communications and human error
				B System rupture/explosion	Yes	
				C Loss of mission	Yes	
	PPS-7 Space based Tug	2	Impact by Meteoroid	A Structural damage	Yes	Meteoroid penetration
				B_1 Potential loss of guidance and control	Yes	
				B_2 Possible loss of communication	Yes	
				C_1 Mission delay	No	
				C_2 Mission loss	Yes	
		3	Impact with space debris	A Structural damage	Yes	Failure to detect debris
				C_1 Delay of mission	No	
				C_2 Loss of mission	Yes	
		4	Loss of command control	A Inability to rendezvous with passive target with transponder out	Yes	Data link failure up/down
				C_1 Mission delay	No	
				C_2 Mission loss	Yes	

Temp-S-3168

MISSION PHASE - ORBITAL PROGRAM ISPLS FMEA NO. 4.3A

REF. FFBD	OPERATIONAL STEP	ITEM NO.	FAILURE MODE	FAILURE EFFECT A - System C - Mission B - Subsystem D - Personnel	HAZARD IDENTIFIED Yes/No	PRIMARY CAUSE
4.0A	Dock propellant module to LSF	1	Impact	A Structural damage	Yes	Failure to brake tug after closure burn
				B Docking ring damaged	Yes	
				C Delay of mission	No	
		2	Docking aids fail	A Render system ineffective	Yes	TV/communications link lost
				B Inoperative	Yes	
				C Loss of mission		
		3	LSF will not stabilize	A Delays docking	No	Disturbance factors
				B Causes misalignment of docking ring	Yes	
				C Delays mission	No	
		4	Docking ring misaligned	A Will not capture	No	Incorrect approach to alignment
				B Possible structural damage	Yes	

Temp-S-3168

MISSION PHASE - ORBITAL PROGRAM ISPLS FMEA NO. 4.4A

REF. FFBD	OPERATIONAL STEP	ITEM NO.	FAILURE MODE	FAILURE EFFECT A - System C - Mission B - Subsystem D - Personnel	HAZARD IDENTIFIED Yes/No	PRIMARY CAUSE
4.0A	Undock from module	1	Docking ring fails to unlatch at passive end	A_1 Tug captive at passive end of propellant module docking ring	No	Mechanical/electrical failure
				A_2 System operative from the active end of propellant module docking ring	No	
				C Delay of mission	No	
		2	Docking ring capture latch hangs up	A Causes disturbance to LSF & Tug	Yes	Alignment at separation incorrect

Temp-S-3168

MISSION PHASE - ORBITAL PROGRAM ISPLS FMEA NO. 4.5A

REF. FFBD	OPERATIONAL STEP	ITEM NO.	FAILURE MODE	FAILURE EFFECT A - System C - Mission B - Subsystem D - Personnel	HAZARD IDENTIFIED Yes/No	PRIMARY CAUSE
4.0A	Maneuver to user port and dock	1	Erratic maneuver	A Possible impact	Yes	Failed control system
				B RCS instability	Yes	
				C Loss of LSF/Tug mission	Yes	
		2	Impact	A Potential fire/explosion	Yes	Avionics control system failure/wrong traffic pattern
				B RCS burn inhibited in wrong direction	Yes	
				C Loss of LSF/Tug mission	Yes	
		3	TV docking aid lost	A Reduced effectiveness	Yes	Electronics failure
				C Delay of mission	No	
		4	Passive vehicle unstable	A Delays docking	No	Undocking disturbance
				B Stabilization subsystem effectiveness reduced	No	
				C Delay of mission	No	
		5	Docking ring mis-aligned	A Will not capture	No	Incorrect approach to alignment
				B Possible structural damage	Yes	
		6	Communications lost	A Inoperative	Yes	Ground net inoperative during operation/IMU failure
				C Loss of mission	Yes	

Temp-S-3168

MISSION PHASE - ORBITAL

PROGRAM ISPLS FMEA NO. 4.6A

REF. FFBD	OPERATIONAL STEP	ITEM NO.	FAILURE MODE	FAILURE EFFECT A - System C - Mission B - Subsystem D - Personnel	HAZARD IDENTIFIED Yes/No	PRIMARY CAUSE
4.0	Transfer/unload propellant module fluid to LSF	1	Failure of line interconnect fixture indexing probes to rigidize fixture	A Renders system inoperative	Yes	Meteoroid shield not retracted/failure of drive mechanism
				B Damage to probes	Yes	
				C Mission delay	No	
		2	Failure of line extension bellows	A_1 Fire/explosion (if confined)	Yes	Mechanical failure
				A_2 Ice crystal cloud formation		
				B Renders subsystem inoperative		
				C Mission delay		
				D Thermal/fragmentation		
		3	Failure of QD to seal	B Leakage at QD	Yes	Contamination/defective seal
		4	Failure of automatically operated electrical connectors to extend	A Renders system inoperative	No	Loss of power/indexing probes misaligned
				C Mission delay	No	
		5	Failure of shutoff valve in closed position	A Propellant will not transfer	No	Failure of shutoff valve solenoid
		6	Structural failure	A Loss of system	Yes	Excessive loads during spin up/vehicle and propellant dynamic interaction
				C Loss of mission	Yes	
				D Loss of personnel	Yes	
		7	Flowmeter fails	A_1 Loss of quantity transfer	Yes	Electro-mechanical failure
				A_2 Loss of CG location	Yes	
				B Flow restriction	No	

Temp-S-3168

MISSION PHASE - ORBITAL PROGRAM ISPLS FMEA NO. 4.6A (Cont.)

REF. FFBD	OPERATIONAL STEP	ITEM NO.	FAILURE MODE	FAILURE EFFECT A - System C - Mission B - Subsystem D - Personnel	HAZARD IDENTIFIED Yes/No	PRIMARY CAUSE
		8	LO_2 regulator to Gas generator fails in open mode	B Excessive temperature in heat exchanger	Yes	Electro-mechanical failure
				C Requires unscheduled shutdown operations	No	
		9	Gas Generator operates erratic	A System becomes inoperative	No	Low pump head pressure
				B_1 Loss of pressurant	No	
				B_2 Pump cavitation	Yes	
		10	Heat Exchanger fails	A System contamination	Yes	Gas generator control failure
				B Functional degradation	Yes	
				C Delay of mission	No	
		11	Source Tank outlet uncovered	A Renders unstable	Yes	Dynamic interaction of vehicle and propellant
				B_1 Possible pump cavitation	Yes	
				B_2 Possible slug flow	Yes	
				C Possible loss of mission	Yes	
				D Subjected to disturbances	Yes	
		12	Distortion of propellant fluid surface	A Causes instability/ structural failure	Yes	Propellant inlet fluid momentum
				C Loss of mission	Yes	

Temp-S-3168

MISSION PHASE - ORBITAL

PROGRAM ISPLS FMEA NO. 4.7A

REF. FFBD	OPERATIONAL STEP	ITEM NO.	FAILURE MODE	FAILURE EFFECT A - System C - Mission B - Subsystem D - Personnel	HAZARD IDENTIFIED Yes/No	PRIMARY CAUSE
4.0A	Transfer propellant from LSF to delivery vehicle Tug	1	Failure of line interconnect fixture indexing probes to rigidize fixture	A Renders system inoperative	Yes	Meteoroid shield not retracted/failure of drive mechanism
				B Damage to probes	Yes	
				C Mission delay	No	
		2	Failure of line extension bellows	A_1 Fire/explosion (if confined)	Yes	Mechanical failure
				A_2 Ice crystal cloud formation		
				B Renders subsystem inoperative		
				C Mission delay		
				D Thermal/fragmentation		
		3	Failure of QD to seal	B Leakage at QD	Yes	Contamination/defective seal
		4	Failure of automatically operated electrical connectors to extend	A Renders system inoperative	No	Loss of power/indexing probes misaligned
				C Mission delay	No	
		5	Failure of shutoff valve in closed position	A Propellant will not transfer	No	Failure of shutoff valve solenoid
		6	Structural failure	A Loss of system	Yes	Excessive loads during spin up/vehicle and propellant dynamic interaction
				C Loss of mission	Yes	
				D Loss of personnel	Yes	
		7	Flowmeter fails	A_1 Loss of quantity transfer	Yes	Electro-mechanical failure
				A_2 Loss of CG location	Yes	
				B Flow restriction	NO	

Temp-S-3168

MISSION PHASE - ORBITAL PROGRAM ISPLS FMEA NO. 4.7A (Cont.)

REF. FFBD	OPERATIONAL STEP	ITEM NO.	FAILURE MODE	FAILURE EFFECT A - System C - Mission B - Subsystem D - Personnel	HAZARD IDENTIFIED Yes/No	PRIMARY CAUSE
		8	LO_2 regulator to Gas generator fails in open mode	B Excessive temperature in heat exchanger	Yes	Electro-mechanical failure
				C Requires unscheduled shutdown operations	No	
		9	Gas Generator operates erratic	A System becomes inoperative	No	Low pump head pressure
				B_1 Loss of pressurant	No	
				B_2 Pump cavitation	Yes	
		10	Heat Exchanger fails	A System contamination	Yes	Gas Generator control failure
				B Functional degradation	Yes	
				C Delay of mission	No	
		11	Source Tank outlet uncovered	A Renders unstable	Yes	Dynamic interaction of vehicle and propellant
				B_1 Possible pump cavitation	Yes	
				B_2 Possible slug flow	Yes	
				C Possible loss of mission	Yes	
				D Subjected to disturbances	Yes	
		12	Distortion of propellant fluid surface	A Causes instability/ structural failure	Yes	Propellant inlet fluid momentum
				C Loss of mission	Yes	

Temp-S-3168

MISSION PHASE – ORBITAL

PROGRAM ISPLS FMEA NO. 4.8A

REF. FFBD	OPERATIONAL STEP	ITEM NO.	FAILURE MODE	FAILURE EFFECT A - System C - Mission B - Subsystem D - Personnel	HAZARD IDENTIFIED Yes/No	PRIMARY CAUSE
4.0A	Undock	1	Tug undocking with line interconnect fixture still attached	A Renders interface inoperative B Potential loss of propellants C Delay of mission	Yes Yes No	Improper procedure/ failed indexing fixture
		2	Pressurization line in interconnect fixture QD fails open after release	A_1 Structural damage A_2 Propellant disturbance	Yes Yes	Contamination/defective seal
		3	Docking ring fails to unlatch	A Tug captive to docking ring	Yes	Mechanical/electrical failure
		4	Docking ring latch hangs up	A Causes disturbance to LSF and Tug	Yes	Separation alignment incorrect
		5	Electrical lines in interconnect fixture not withdrawn before separation	A Damaged for next use B Possible bent/failed pins C Mission lost on next operation	Yes Yes Yes	Incorrect procedure

Temp-S-3168

MISSION PHASE - ORBITAL

PROGRAM ISPLS   FMEA NO. 4.9A

REF. FFBD	OPERATIONAL STEP	ITEM NO.	FAILURE MODE	FAILURE EFFECT A - System C - Mission B - Subsystem D - Personnel	HAZARD IDENTIFIED Yes/No	PRIMARY CAUSE
4.0A	Retrieve empty propellant module	1	Errotic maneuver	A Possible impact B RCS instability C Loss of LSF/Tug mission	Yes Yes Yes	Failed control system
		2	Impact	A Potential fire/explosion	Yes	Avionics control system failure/wrong traffic pattern
				B RCS burn inhibited in wrong direction C Loss of LSF/Tug mission	Yes Yes	
		3	TV docking aid lost	A Reduced effectiveness C Delay of mission	Yes No	Electronics failure
		4	Passive vehicle unstable	A Delays docking B Stabilization subsystem effectiveness reduced C Delay of mission	No No No	Undocking disturbance
		5	Docking ring mis-aligned	A Will not capture B Possible structural damage	No Yes	Incorrect approach to alignment
		6	Communications lost	A Inoperative C Loss of mission	Yes Yes	Ground net inoperative during operation/IMU failure
		7	Tug undocking with line interconnect fixture still attached	A Renders interface inoperative B Potential loss of propellants C Delay of mission	Yes Yes No	Improper procedure/failed indexing fixture

Temp-S-3168

MISSION PHASE - ORBITAL PROGRAM ISPLS FMEA NO. 4.9A (Cont.)

REF. FFBD	OPERATIONAL STEP	ITEM NO.	FAILURE MODE	FAILURE EFFECT A - System C - Mission B - Subsystem D - Personnel	HAZARD IDENTIFIED Yes/No	PRIMARY CAUSE
		8	Pressurization line in interconnect fixture QD fails open after release	A_1 Structural damage	Yes	Contamination/defective seal
				A_2 Propellant disturbance	Yes	
		9	Docking ring fails to unlatch	A Tug captive to docking ring	Yes	Mechanical/electrical failure
		10	Docking ring latch hangs up	A Causes disturbance to LSF and Tug	Yes	Separation alignment incorrect
		11	Electrical lines in interconnect fixture not withdrawn before separation	A Damaged for next use	Yes	Incorrect procedure
				B Possible bent/failed pins	Yes	
				C Mission lost on next operation	Yes	

Temp-S-3168

MISSION PHASE - ORBITAL PROGRAM ISPLS FMEA NO. 4.11A

REF. FFBD	OPERATIONAL STEP	ITEM NO.	FAILURE MODE	FAILURE EFFECT A - System C - Mission B - Subsystem D - Personnel	HAZARD IDENTIFIED Yes/No	PRIMARY CAUSE
4.0A	Rendezvous with Orbiter (PPS-5 & PPS-7)	1	Terminal phase finalization braking not effective	A Impact with Orbiter C Possible mission loss D Possible loss of personnel	Yes Yes	Failure of braking system (APS) controls
	PPS-5 Centaur PPS-7 Space based Tug	2	Attitude hold control ineffective	A_1 Cannot effect transfer of down module A_2 System effectiveness lost	No Yes	Control failure
		3	Stabilization system failure	A_1 Renders tug inoperative A_2 System effectiveness lost	No Yes	Control failure
		4	Impact	A Structural damage C Possible mission loss D Possible loss of personnel	Yes Yes Yes	Closure burn excessive

Temp-S-3168

MISSION PHASE - ORBITAL PROGRAM ISPLS FMEA NO. 4.12A

REF. FFBD	OPERATIONAL STEP	ITEM NO.	FAILURE MODE	FAILURE EFFECT A - System C - Mission B - Subsystem D - Personnel	HAZARD IDENTIFIED Yes/No	PRIMARY CAUSE
4.0A	Stand off from Shuttle Orbiter PPS-7	1	Translation control ineffective	A May create a pitch or yaw condition causing impact with Shuttle manipulators C Delay of mission D Subjected to disturbances	Yes No Yes	Intermittent RCS operation of one set of engines
	PPS-7 Space based Tug	2	Impact	A Structural damage C Delay of mission D Subjected to disturbances		Erroneous control signal/ human error

Temp-S-3168

MISSION PHASE - PRELAUNCH PROGRAM ISPLS FMEA NO. 2.3B

REF. FFBD	OPERATIONAL STEP	ITEM NO.	FAILURE MODE	FAILURE EFFECT A - System C - Mission B - Subsystem D - Personnel	HAZARD IDENTIFIED Yes/No	PRIMARY CAUSE
2.0B	Perform launch operations and launch	1	Structure fails at J weld	A Loss of system C Loss of mission	Yes	Overstress during childown
		2	Fails to maintain tank pressure	A Loss of structural integrity during first stage boost	Yes	LO_2 pressurization system failure
		3	LO_2 recirculation helium injection supply lost	A Potential loss of integrity of LO_2 pump B Gas collection in pump due to loss of circulation	Yes Yes	Low pressure regulator failure

Temp-S-3168

MISSION PHASE - LAUNCH AND ASCENT PROGRAM ISPLS FMEA NO. 2.4B

REF. FFBD	OPERATIONAL STEP	ITEM NO.	FAILURE MODE	FAILURE EFFECT A - System C - Mission B - Subsystem D - Personnel	HAZARD IDENTIFIED Yes/No	PRIMARY CAUSE
2.0B	Perform mated ascent	1	Structural failure	A Loss of LH_2 tank structural integrity	Yes	Loss of ullage pressure to less than 27.5 psia at max Q
				C Loss of mission	Yes	
		2	Main engines fail to start	A Possible contact with the booster vehicle's stabilizer	Yes	Prevalves failing closed
				C Loss of mission	Yes	
				D Possible loss of crew	Yes	
		3	Loss of engine compartment heat shield	A Possible loss of OMS capability	Yes	Material defect
				C Loss of mission	Yes	
				D Potential loss of booster crew	Yes	
		4	Premature ordnance activation	A Loss of capability	Yes	Electrical/electronics
				C Loss of mission	Yes	
				D Potential loss of crew in booster	Yes	
		5	"Open" dual parallel main tank vent valves	A Reduced capability	Yes	Inadvertently activated
				B Main engines become inoperative	Yes	
				C Loss of mission	Yes	
				D Possible impact with booster verticle stabilizer	Yes	
		6	Abort separation	A Possible instability	Yes	Absence of aerodynamic stability in ESS at abort separation
				C Mission loss	No	
				D Possible exposure to fragmentation or blast	Yes	

Temp-S-3168

MISSION PHASE - ORBITAL PROGRAM ISPLS FMEA NO. 2.5B

REF. FFBD	OPERATIONAL STEP	ITEM NO.	FAILURE MODE	FAILURE EFFECT A - System C - Mission B - Subsystem D - Personnel	HAZARD IDENTIFIED Yes/No	PRIMARY CAUSE
2.0B	Perform booster/ ESS staging	1	Structural failure	A Loss of system	Yes	Impact with booster at separation
				C Loss of mission	Yes	
				D Potential loss of booster crew	Yes	
		2	Failure to receive booster near-depletion signal (LO_2 sensors)	A ESS engines do not start	Yes	
				B ESS computer fails to begin separation control	Yes	Main computer input loss
				C Loss of mission	Yes	
				D Emergency separation must be effected by crew	Yes	
		3	Range safety distruct package fires on arming	C Loss of mission	Yes	Electrical/electronics failure
				D Potential loss of booster and crew	Yes	
		4	Stabilization control lost	A Loss of abort capability	Yes	DCM computer in ESS fails
				C Loss of mission	Yes	
		5	Loss of pressurization in tankage	A Reduces capability	No	Vent valve fails open
				B Engines fail to start	Yes	
				C Loss of mission	Yes	
				D Potential loss of booster and crew	Yes	
		6	LH_2 recirculation return valve fails closed	B Propulsion system inoperative	Yes	Failure in the stage sequence controller
				C Loss of mission	Yes	
				D Possible loss of booster crew	Yes	
		7	Improper separation technique	D Increase in noise and temperature level on booster in area of crew	Yes	Failure of booster to stay out of the ESS exhause plume

Temp-S-3168

MISSION PHASE PROGRAM ISPLS FMEA NO. 2.6B

REF. FFBD	OPERATIONAL STEP	ITEM NO.	FAILURE MODE	FAILURE EFFECT A - System C - Mission B - Subsystem D - Personnel	HAZARD IDENTIFIED Yes/No	PRIMARY CAUSE
2.0B	Achieve mission orbit	1	Loss of thrust	A Requires abort	Yes	Vent valve fails open
				B Loss of main engines thrust	Yes	
				C Loss of mission	Yes	
				D May cause potential for loss of booster & crew	Yes	
		2	Structural failures	A Loss of LH_2 tank	Yes	Failure to achieve vent valve low mode pressure (27.5 psia) at cutoff
				B Inoperative	Yes	
				C Loss of mission	Yes	
		3	Undesired propulsive force applied	A Loss of RCS capability	Yes	Propulsive vent valve fails open
				B Imparts undesired velocity component to attitude of ESS	Yes	
		4	OMS engine inopera-tive	A Degradation of capability	Yes	OMS engine thrust chamber feed valve (O_2 and H_2) fails to open
				C Mission failure	Yes	
		5	Loss of OMS engine	A Degradation of system	Yes	Turbopump gas generator O_2 and H_2 pressure regulator fails (high or low)

Temp-S-3168

MISSION PHASE - ORBITAL PROGRAM ISPLS FMEA NO. 3.1B

REF. FFBD	OPERATIONAL STEP	ITEM NO.	FAILURE MODE	FAILURE EFFECT A - System C - Mission B - Subsystem D - Personnel	HAZARD IDENTIFIED Yes/No	PRIMARY CAUSE
3.0B	Perform rendezvous maneuver	1	Loss of communications	A_1 Loss of up data link	Yes	Failure in the switching units
				A_2 Loss of deorbit capability	Yes	
				A_3 Loss of ranging data	Yes	
				A_4 Loss of rendezvous commands	Yes	
				C Reduced mission capability	No	
		2	Fails to stabilize	A Precludes operational docking	Yes	Loss of RCS capability
				C Mission loss	Yes	
		3	Impact with debris	A System loss	Yes	Debris in flight path
				C_1 Loss of mission	Yes	
				C_2 Decreased mission capability	No	
		4	OMS engine fails to produce thrust	A Reduced capability	Yes	Selector valve fails to allow flow to OMS engine
				B System inoperative	No	
				C Loss of mission	Yes	
		5	OMS engine cutoff early	A Precludes proper rendezvous	No	Premature depletion signal
		6	OMS engine fail to cutoff	A Possible impact with target	Yes	Failure in propellant management subsystem
		7	Range safety propellant disperson system activates	A Destruction	Yes	Erroneous command from computer
				C Loss of mission	Yes	

Temp-S-3168

REF. FFBD	OPERATIONAL STEP	ITEM NO.	FAILURE MODE	FAILURE EFFECT A - System C - Mission B - Subsystem D - Personnel	HAZARD IDENTIFIED Yes/No	PRIMARY CAUSE
		8	Premature separation of propellant tank	A Possible loss of capability to rendezvous C Possible loss of mission	No Yes	Failure of the separation control system

Temp-S-3168

MISSION PHASE PROGRAM ISPLS FMEA NO. 3.2B

REF. FFBD	OPERATIONAL STEP	ITEM NO.	FAILURE MODE	FAILURE EFFECT A - System C - Mission B - Subsystem D - Personnel		HAZARD IDENTIFIED Yes/No	PRIMARY CAUSE
3.0B	Prepare for user docking	1	Fails to stabilize	B	GN&C integrity reduced	Yes	Thrusters inoperative due to propellant loss
				C	Loss of mission	Yes	
		2	Impact	A	Reduced integrity	Yes	Improper docking alignment of CIS
				B	Propellant transfer system damage	Yes	
				C	Potential loss of mission	No	
		3	Docking aids	A	Reduced integrity	Yes	Loss of TV and/or transponder
				B	Renders inoperative	No	
		4	Tank vents during docking approach	A	Obscures area with ice crystals	Yes	Pressure relieving of propellant tankage

Temp-S-3168

MISSION PHASE PROGRAM ISPLS FMEA NO. 4.1B

REF. FFBD	OPERATIONAL STEP	ITEM NO.	FAILURE MODE	FAILURE EFFECT A - System C - Mission B - Subsystem D - Personnel	HAZARD IDENTIFIED Yes/No	PRIMARY CAUSE
4.0B	Prepare for transfer operation	1	Meteoroid shield does not retract	A Renders system inoperative	Yes	Mechanical failure
				B Damage to probes	Yes	
				C Delay of mission	No	
		2	Indexing probe fails to extend	A System inoperative	No	Electro-mechanical failure of drive mechanism
				B Transfer cannot be effected	No	
				C Mission delay	No	
		3	Electrical probe fails to make contact	A Inoperative	No	Failure of probe extension device
				B Inoperative	No	
				C Delay/loss of mission	No	
		4	Extension bellows on interconnect fixture fluid lines fail	A Potential fire/explosion	Yes	Fatigue/defective material
				B Inoperative	Yes	
				C Loss of mission	No	
		5	Pressurization line QD leaking	A Possible undesired movement of system	Yes	Seal damage
				B Possible propulsion venting	Yes	
		6	Propellant line isolation valve fails closed	A Renders system inoperative	No	Electro-mechanical
				B Loss of transfer capability	No	
				C Delay/loss of mission	Yes	
		7	Probe extension drive fails to extend probes	A Renders system inoperative	No	Electrical failure
				B Loss of transfer capability	No	
				C Delay/loss of mission	No	

Temp-S-3168

MISSION PHASE PROGRAM ISPLS FMEA NO. 4.2B

REF. FFBD	OPERATIONAL STEP	ITEM NO.	FAILURE MODE	FAILURE EFFECT (A - System, B - Subsystem, C - Mission, D - Personnel)		HAZARD IDENTIFIED Yes/No	PRIMARY CAUSE
4.0B	Transfer propellants	1	Configuration disturbance during linear acceleration	A	Potential structural failure	Yes	Loss of attitude control
		2	Structural failure	B	Line/tank rupture	Yes	Overstress at childown
		3	Explosion	A	Loss of system	Yes	Leak in confined area
		4	Internal sparking	A	Potential fire/explosion		Loss of grounding capability
		5	Flow meter fails to measure flow	C	Insufficient fluids to accomplish mission	Yes	Electronics failure
		6	CG falls inside receiver vehicle	A	Causes two phase flow in vent return line	Yes	Configuration loaded without adequate CG consideration

Temp-S-3168

MISSION PHASE - ORBITAL PROGRAM ISPLS FMEA NO. 4.3B

REF. FFBD	OPERATIONAL STEP	ITEM NO.	FAILURE MODE	FAILURE EFFECT A - System C - Mission B - Subsystem D - Personnel	HAZARD IDENTIFIED Yes/No	PRIMARY CAUSE
4.0B	Terminate transfer operation	1	Failure to purge lines of locked up fluids	A Renders inoperative B Destroys subsystem operational capability C Mission delay	No Yes No	Improper procedure
		2	Main fuel lines shutoff valve fails to close	A No effect B Quick disconnect function of shutoff valve	No	Loss of signal or mechanical failure
		3	Pressurization QD leaks at separation (ESS/Tank)	A Implosion of system at re-entry B Loss of tank pressurization	Yes Yes	Mechanical failure/ contamination
		4	Indexing probes fail to retract	A Precludes separation B Renders subsystem inoperative	Yes	Mechanical failure

Temp-S-3168

MISSION PHASE - ORBITAL   PROGRAM ISPLS   FMEA NO. 6.1B

REF. FFBD	OPERATIONAL STEP	ITEM NO.	FAILURE MODE	FAILURE EFFECT A - System C - Mission B - Subsystem D - Personnel	HAZARD IDENTIFIED Yes/No	PRIMARY CAUSE
6.0B	Undock user from ESS/prop tank	1	Latching device fails to release	A Precludes separation B Renders inoperative	Yes Yes	Mechanical failure
		2	Separation fouled by one latching lug	A Subjected to disturbance B May cause structural damage to locking device C Delay of mission	Yes Yes No	Mechanical failure
		3	Thrusts on ESS activate inadvertently	A Could cause impact damage C Mission delay	Yes No	Computer malfunction or human error
		4	User impacts ESS	A Could cause impact damage C Delay of mission	Yes No	Improper thrusters commanded by human error

Temp-S-3168

MISSION PHASE - DEORBIT PROGRAM ISPLS FMEA NO. 6.2B

REF. FFBD	OPERATIONAL STEP	ITEM NO.	FAILURE MODE	FAILURE EFFECT A - System C - Mission B - Subsystem D - Personnel	HAZARD IDENTIFIED Yes/No	PRIMARY CAUSE
6.0B	Perform ESS deorbit to earth impact	1	Fails to attain proper deorbit orientation	A System rendered unstable C Possible impact outside of footprint	Yes	Failure of Avionics System
		2	OMS engine fails to burn	A Causes random reentry B Propellants lost	Yes Yes	Failure of turbopump propellant shutoff valve to close
		3	Thrusters fail on activation	A Causes random reentry B Propellants lost	Yes Yes	Failure of turbopump propellant shutoff valve to close
		4	Initiation of retro-burn delayed	A Entry may overshoot the footprint	Yes	Sluggish valve operation
		5	Fails to hold attitude until engine retro burn cutoff	A System becomes disoriented C Impact outside of footprint	Yes Yes	Avionics failure
		6	ESS/Tank separates during reentry	A Reduces stability of system C Potential impact outside footprint	Yes	Separation device activation
		7	Implosion/explosion	A Destroyed C Potential impact of debris outside footprint	No Yes	Tanks vented to vacuum

Temp-S-3168

APPENDIX C

HAZARD ANALYSIS SHEETS

This appendix includes those hazards identified and associated with the representative orbital propellant logistic operations described in Appendix A. Potential hazards directly related to those identified by the FMEA's plus operational and interface hazards associated with a particular functional block, are structured to present the hazards as they flow through the functional blocks identified in Appendix A.

Definition of Safety Terms

The following terms used in this document are defined as follows:

a. Hazard - The presence of a potential risk situation caused by an unsafe act or condition.

b. Risk - The potential for injury or loss of personnel, equipment or property.

c. Major damage - Damage by unprogrammed or unscheduled events which results in major system degradation or loss.

d. Major system degradation - A condition which results in one or more of the following:

(1) Jeopardized achievement of an operation or performance of a mission; or delay beyond acceptable time limits.

(2) Inadvertent system activation.

Hazard Groups

There were 12 hazard groups used in the study. These are representative of the hazards which could be broadly grouped from the various phases of the missions and operations of the representative orbital propellant logistic concept. Because of the broad grouping, the reader may note considerable interaction or overlap between the selected groups. Assignment of a hazard to the hazard groups was made by the individual system safety engineer and, in some cases, is grouped by a purely arbitrary decision, which is not uncommon in such cases.

1. Fire/Explosion/Implosion

This group includes hazards which are created by chemical reactions, catalytic action, frictional effects, or other heat generating principles, where fire can be initiated by hypergolic action or initiating source.

It further includes explosions initiated by fire or spark and those which are not necessarily fire initiated such as overpressurization, instantaneous release of high pressures by container fracture, or reactions in ambient conditions where gaseous hydrogen and oxygen are combined in quantities of 4 and 2 percent by volume respectively, or greater, and the resulting mixture is subjected to pressures of 2 mm of Mercury or more and subjected to initiation source, such as catalytic reaction with nickel, zirconium, etc., impact or spark.

Implosion includes those hazards in which an adverse ΔP is created across a structure (tank) by reducing internal pressure such as during drainage of fluid from a locked up volume, cryo-pumping, or venting to vacuum and locking the tank up for re-entry into the earth's atmosphere.

2. Reduced Integrity of Structure or Equipment

This group includes conditions which subject a structure or equipment to some level of degradation, such as possible adverse stress due to exposure to extreme temperature slugging, damage, scrubbing interaction between fluids and materials, reduction in critical characteristics or materials capability, functional degradation or loss of supporting equipment, and out of sequence operations. (1) Loss of pressurization, (2) thermal shock, (3) failure of line interconnect fixtures, (4) leakage or mass spill, (5) loss of liquid vapor interface control, and (6) degradation of manned elements are sub groups. Parentheses ( ) indicate sub group code.

3. Contamination

This group includes hazards related to those conditions producing or introducing contamination. The amount of the contaminating media includes that which is needed to create the contamination and ranges from traces to large particulates. Products of combustion, ice crystals, and metal chips are examples.

4. Corrosion

This group includes those conditions which adversely damage personnel or material surfaces by chemical attack.

5. Toxicity

This group includes hazards related to production of a toxic substance which affects the human body adversely.

6. Heat and Temperature

This group includes those conditions related to excursions of temperature bracketing extreme heat to extreme cold.

7. Loss of Thrust

This group covers those cases where loss of thrust is experienced when needed for scheduled operations. It includes main and auxiliary propulsion engines and propulsive vents.

8. Unscheduled Vehicle Impact

This group includes impact hazards involving loss of target by the vehicle avionics or ground net, meteoroid and/or space debris with the vehicle, mechanical failures or delays in valve actuation for any reason, loss of docking aids or incorrect approach alignment and inadvertent or misoperation of RCS, propulsive vents, etc. Manipulator related hazards such as loss of TV and lighting, cargo with structure impacts and damage caused by sloshing or unstabilizing effects are also included. Human error has been included in the group as related to impacts while exercising manual control of the vehicle or introduction of commands for remote activation.

9. Loss of Attitude Control

This group includes those hazards where the inability to achieve stabilization for any reason prevails, such as lack of or intermittent RCS operation, CG shift during rotation. This also includes the conditions where application or release of tension loads causes instability within the configuration for any time duration, without damping.

10. Loss of Habitable Environment

This group includes any condition which, through its occurrence, would render the manned volume unfit for unsuited occupancy. Such conditions include hazards such as decompression by penetration, long-term leakage or seal failures which give unscheduled depletion of oxygen supply, contamination, heat, humidity and loss of CO_2 control.

11. Loss of Communication

This group includes loss of ability to send or receive programmed data under operational conditions. It encompasses radio, radar, laser, TV, hard wire communications and necessary equipment, GSE, facilities or satellites associated with the communication process.

12. Disturbances

Included in this hazard group are those conditions which can affect stability conditions adversely, such as sloshing and CG shift coupling with the dynamics of the vehicle or configuration, RCS interaction therewith, tank inlet fluid momentum distorting the liquid surface, or combinations initiating such conditions, including impact and wobble. (1) Sloshing, (2) dynamic coupling, (3) loss of

CG control, and (4) uncontrolled venting are sub groups. Parentheses ( ) indicate the sub group code.

Hazard Analysis Form Description

The continuity of story flow through the representative orbital propellant logistic operation is maintained in the use of the Hazard Analysis form. This comes about in the manner in which the operation/phase is described; i.e., as the function is described in the FFD for those referenced under the heading "References."

Potential hazards identified with their effects have been described and are contained herein. The material then was reviewed for corrective measures required for description of action recommended.

The complete story is thus contained on the Hazard Analysis form, when used in conjunction with the applicable FFD which has the same reference number as the HA reference.

The code for the Hazard Analysis forms used in the ISPLS Study involving operation/phase, hazard group and subsystem is as follows:

Operation/ Phase	Code	Hazard Group	Code	Subsystem	Code
Prelaunch	A	Fire/Explosion/Implosion	1	Avionics	1
		Reduced Integrity of Structure or Equipment	2	Propulsion	2
Launch/ Ascent	B	Contamination	3	Vehicle Support	3
		Corrosion	4	Mechanical	4
Orbital	C	Toxicity	5	Structural	5
		Heat/Temperature	6	Materials	6
Deorbit	D	Loss of Thrust	7	GSE	7
		Unscheduled Vehicle Impact	8	Facilities	8
Landing	E	Loss of Attitude Control	9	Payload	9
		Loss of Habitable Environment	10	Safing	10
Safing	F	Loss of Communication	11	Propellant	11
		Disturbances	12	Human	12
				Pressurization	13

The Hazard Classes used are those categorized in OMSF Safety Program Directive #1, Revision A, dated December 12, 1969, re-stated here in modified form for purposes of this conceptual study. See Table C-1.

HAZARD CLASS	MISSION GOALS	SYSTEM SAFETY	FACILITY SAFETY	CREW SAFETY
Catastrophic	Mission Loss	Vehicle Loss or Extensive Damage	Loss or Considerable Facility Damage	Multiple Injury or Death
Critical	Major Degradation	Substantial Equipment Loss	Substantial Loss	Injury
Marginal	Minor Degradation	Minor Equipment Loss	Minor Loss	Can be Controlled to Prevent Injury
Negligible	No Effect	No Loss	No Loss	No Injury

Table C-1

The action recommended covers one or more recommended means to eliminate or reduce the hazard. If the hazard cannot practically be eliminated the actions for reducing the hazard in order of precedence are those contained in OMSF Safety Program Directive No. 1, Revision A, condensed here for convenience of the reader.

a. Design for minimum hazard.

b. Use appropriate safety devices.

c. Provide devices for timely detection of the condition and generation of adequate warning signals.

d. Develop special procedures to counter the hazardous condition and enhance personnel safety.

e. Residual hazards shall be those for which none of the above actions are effective in counteracting the hazard and shall be justified and documented.

Identified Hazards

Hazards identified with the representative orbital propellant logistic operations baseline are included in hazard sheets 1 through 77. The variation to the baseline where the tug shares the delivery function with the orbiter in supporting the large storage facility with propellants has the delta operations hazards identified on hazard sheets 78 through 132. Hazards identified with the Booster/ESS variation to the baseline are contained in hazard sheets 133 through 179.

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED ______

OPERATIONAL HAZARD ANALYSIS

PAGE ____ OF ____
DATE ______
REV ______

END ITEM Shuttle | **SUBSYSTEM** Facilities | **SUBSYSTEM IDENT NO.** 8

OPERATION/PHASE Prelaunch-Prepare support equipment and propellant area | **OP. IDENT. NO.** A

HAZARD GROUP Fire/Explosion, reduced integrity | **HAZARD GRP. CODE** 1, 2

REFERENCES FMEA 2.3.4.3 | **AUTHORITY** Task II-3

HAZARD DESCRIPTION/ EFFECTS Overstressing and rupture of facility lines during chilldown for LH_2 transfer to hydrogen slush manufacturing facility would cause the propellant storage tank to drain rapidly, creating a mass spill at the point of rupture and may reduce ullage pressure to the point of implosion of the tankage. Tank isolation remains a means of preventing this implosion. The LH_2 system will be involved in fire and possible explosion and will present an area control problem which may involve fire. Cryogens will create hazards for any personnel in the immediate area and structures involved in the mass spill will be stressed.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			Critical

COPIES TO: STRUCTURAL ____ MECHANICAL X MATERIALS ____ GSE X OTHER ____

AVIONICS ____ PROPULSION ____ VEHICLE SUPPORT ____ FACILITIES X PAYLOAD ____ SYS SAFETY X

ACTION RECOMMENDED: Provide a tank isolation valve at the line inlet to the tank which is capable of remote/automatic operation under emergency conditions. Provisions should be incorporated to provide a compatible make-up gas to minimize negative ullage pressure. Procedurally require facility access control and have area clearance prior to conducting chilldown or transfer operations.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				Marginal

1

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED ____

OPERATIONAL

HAZARD ANALYSIS

PAGE ____ OF ____

DATE ____

REV ____

END ITEM Cargo Module	**SUBSYSTEM** Mechanical	**SUBSYSTEM IDENT NO.** 4
OPERATION/PHASE Prelaunch - Stow perishables and hazardous cargo		**OP. IDENT. NO.** A
HAZARD GROUP Contamination/Corrosive/Toxicity/Fire		**HAZARD GRP. CODE** 3, 4, 5, 1
REFERENCES FMEA 2.3.4.6		**AUTHORITY** Task II-3

HAZARD DESCRIPTION/ EFFECTS During the payload handling of tanks containing LN_2, N_2H_4 and H_2O_4 damage by impact or rough handling could cause leakage at seals or valving. Leakage may not be readily detectable by personnel, but during the storage in the orbiter cargo bay prior to launch damage in the form of corrosion and contamination could occur if not detected. Toxicity and fire could impact handling personnel and shuttle orbiter, respectively.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			Marginal

COPIES TO: STRUCTURAL ____ MECHANICAL ____ MATERIALS ____ GSE ____ OTHER ____

AVIONICS ____ PROPULSION ____ VEHICLE SUPPORT X FACILITIES ____ PAYLOAD ____ SYS SAFETY X

ACTION RECOMMENDED: Guides and handling fixtures should be designed and used for each type of payload. Procedural controls and training should be implemented to minimize handling damage. If accidental impact does occur the cargo should be inspected for damage or leakage prior to loading. Provide an inert gas purge of the cargo bay during ground loading. Provide detection devices with read-out in the orbiter checkout and fault isolation system which monitors the various hazardous concentrations within the cargo module and within the cargo bay.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				Negligible

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED ____

OPERATIONAL HAZARD ANALYSIS

PAGE 1 OF 1

DATE ____

REV ____

END ITEM Propellant Module	SUBSYSTEM Tank Structure	SUBSYSTEM IDENT NO. 5
OPERATION/PHASE	Prelaunch - Precondition and Sample Module LH_2 Tanks	OP. IDENT. NO. A
HAZARD GROUP	Fire and Explosion	HAZARD GRP. CODE 1
REFERENCES	FMEA 2.3.4.13	AUTHORITY Task II-3

HAZARD DESCRIPTION/ EFFECTS

During preconditioning of a LH_2 slush propellant module tank, the collapse of the ullage pressure could cause tank implosion if ullage makeup pressure is insufficient or lost. The effects would be fire or explosion of the module within the orbiter cargo bay.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			Catastrophic

COPIES TO: STRUCTURAL ____ MECHANICAL ____ MATERIALS ____ GSE X OTHER ____

AVIONICS ____ PROPULSION ____ VEHICLE SUPPORT ____ FACILITIES X PAYLOAD X SYS SAFETY X

ACTION RECOMMENDED:

Provide automatic controls for sensing pressure drops in tank ullage, which will activate conditioning flow cutoff and increase ullage pressure gas flow until ullage pressure increases to a safe level.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				Marginal

3

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED

OPERATIONAL

HAZARD ANALYSIS

DATE

REV

END ITEM
Propellant Module

SUBSYSTEM
Propellant Fill/Drain System

SUBSYSTEM IDENT NO.
2

OPERATION/PHASE
Prelaunch - Perform propellant loading

OP. IDENT. NO.
A

HAZARD GROUP
Fire/Explosion, Reduced Integrity of Structure or Equipment

HAZARD GRP. CODE
1,2

REFERENCES
FMEA 2.4.1 Ref. 19A

AUTHORITY
Task II-3

HAZARD DESCRIPTION/ EFFECTS

Failure of the propellant fill system to keep slush LH_2 moving through the lines at speeds greater than the critical velocity may cause ice blockage within the feed lines, restricting further flow. Under conditions where this ice blockage breaks up under increased pressure, internal tank damage to baffles, sensors, etc., could conceivably occur due to impact or scrubbing of large ice chunks. The effects of line blockage could be line rupture causing fire or explosion within the facility or orbiter cargo bay, and thermal stressing of structural members.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			Catastrophic

COPIES TO: STRUCTURAL ___ MECHANICAL ___ MATERIALS ___ GSE X OTHER ___

AVIONICS ___ PROPULSION ___ VEHICLE SUPPORT ___ FACILITIES X PAYLOAD X SYS SAFETY X

ACTION RECOMMENDED:

Insure the propellant feed system is designed and operated such as to prevent non-homogenous mixtures of slush LH_2. Procedural techniques should be developed to stop slush flow if the quality of the delivered slush deteriorates.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				Marginal

4

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED

INTERFACE
HAZARD ANALYSIS

PAGE 1 OF 1
DATE
REV

END ITEM Propellant Module	SUBSYSTEM Propellant Tank	SUBSYSTEM IDENT NO. 11
OPERATION/PHASE Prelaunch - Perform propellant loading		OP. IDENT. NO. A
HAZARD GROUP Fire/explosion, reduced integrity of structure or equipment		HAZARD GRP. CODE 1,2
REFERENCES FMEA 2.4.1, Ref 1		AUTHORITY Task II-3

HAZARD DESCRIPTION/ EFFECTS The propellant module tank could become overpressurized if HPI Helium blanket is lost during or after propellant loading (Slush LH_2) depending upon tank configuration. **Rapid** heat transfer into the tank may cause expanded fluids to exceed the tank vent capability. If unmonitored or undetected the expansion may rupture the tank causing fire/explosion within the orbiter cargo bay. This condition is for tanks with external insulation, but no internal insulation.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			Catastrophic

COPIES TO: STRUCTURAL ___ MECHANICAL ___ MATERIALS ___ GSE X OTHER ___

AVIONICS X PROPULSION ___ VEHICLE SUPPORT ___ FACILITIES ___ PAYLOAD X SYS SAFETY X

ACTION RECOMMENDED:

Provide emergency vent/relief valve for credible loss of insulating capability and off-load capability for the propellant module while emplaced in the orbiter cargo bay.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				MARGINAL

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED ______

OPERATIONAL
HAZARD ANALYSIS

DATE ______
REV ______

END ITEM Propellant Module

SUBSYSTEM Propellant Tank

SUBSYSTEM IDENT NO. 2

OPERATION/PHASE Prelaunch - Perform propellant loading

OP. IDENT. NO. A

HAZARD GROUP Fire/explosion, reduced integrity of structure or equipment

HAZARD GRP. CODE 1,2

REFERENCES FMEA 2.4.6

AUTHORITY Task II-3

HAZARD DESCRIPTION/ EFFECTS The failure of a feedline quick disconnect to seat (on airborne half of connector) upon disconnecting the line at the propellant module would provide the source of a hazard for both a fire/explosion or cryostressing of structural members. Contamination in the form of metal particles or corrosion could be the cause of failure. In light weight tanks, the rapid drainage of the propellant from a locked up tank could cause tank implosion with resultant fire/explosion. On the launch pad and with the Shuttle orbiter cargo bay doors closed, the hazardous condition could be expected to delay the mission if a minor leak and cause loss of the vehicle and mission if a major leak occurs.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			Catastrophic

COPIES TO: STRUCTURAL ___ MECHANICAL ___ MATERIALS ___ GSE ___ OTHER ___

AVIONICS ___ PROPULSION ___ VEHICLE SUPPORT ___ FACILITIES ___ PAYLOAD ___ SYS SAFETY X

ACTION RECOMMENDED: Provide an automatic shut-off valve between the tank and QD which will be procedurally closed prior to separation of the QD. The isolated segment of line (QD to valve) should be provided relief capability for relief of locked-up pressure therein. The cargo bay should be purged on a continuous basis with an inert gas while on the pad, with the propellant module loaded. Provide a compatible make-up gas for tank ullage pressure.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				NEGLIGIBLE

6

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED

OPERATIONAL

HAZARD ANALYSIS

PAGE 1 OF 1

DATE

REV

END ITEM Shuttle Orbiter	SUBSYSTEM Propellant loading	SUBSYSTEM IDENT NO. 11
OPERATION/PHASE Prelaunch - Perform mission abort operations		OP. IDENT. NO. A
HAZARD GROUP Fire/Explosion		HAZARD GRP. CODE 1
REFERENCES FMEA 2.4, Opnl Step 7.0, Item 1		AUTHORITY Task II-3

HAZARD DESCRIPTION/ EFFECTS The hazard involved in failure of the emergency propellant off-load capability can create effects varying from none to potentially catastrophic, depending on the configuration status & time in the launch countdown. After the Hydrogen vent disconnect & propellant fill disconnects are disconnected & swung away or if not disconnected, but the fill & drain line valve cannot be actuated to "open", the LOX tank can be vented to atmosphere and the LH_2 tank can be vented through the pull-away emergency depressurization disconnect. This mode of off-loading could be catastrophic if the reason for the abort were fire in another subsystem or an electrical storm passed in the area during the venting cycle. In the event a propellant module was stowed in the cargo bay, additional fire hazards can be expected from a LH_2 slush-filled module, from heat transfer beyond the design limit.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS Catastrophic

COPIES TO: STRUCTURAL ___ MECHANICAL ___ MATERIALS ___ GSE ___ OTHER ___

AVIONICS ___ PROPULSION ___ VEHICLE SUPPORT ___ FACILITIES ___ PAYLOAD ___ SYS SAFETY X

ACTION RECOMMENDED:

Provide inert gas atmosphere for cargo bay of shuttle and remotely actuated re-connect capability for LOX and LH_2 vent disconnects and fill and drain disconnect.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO MARGINAL

7

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED ______

INTEGRATION

HAZARD ANALYSIS

DATE ______

REV ______

END ITEM Shuttle Orbiter/Booster	SUBSYSTEM Propellant Lines	SUBSYSTEM IDENT NO. 11
OPERATION/PHASE Launch - Perform initial ascent maneuver		OP. IDENT. NO. B
HAZARD GROUP Fire/Explosion		HAZARD GRP. CODE 1
REFERENCES FMEA 2.6.1		AUTHORITY Task II-3

HAZARD DESCRIPTION/ EFFECTS Structural failure of propellant line bellows or the feed lines will create a catastrophic condition internal to the Shuttle orbiter. Any failure could be expected to result in a fire or explosion which would destroy the vehicle with loss of crew and personnel. This condition can be created by overstress of the bellows in a localized area due to a "ding" or "crease", improper weld joint, corrosion or metal fatigue. The effect would be loss of engine thrust and explosive vapor buildup with subsequent explosion. Fire would result if the line ruptured outside of the vehicle structure in the engine compartment, depending on the ambient pressure at time of rupture.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			Catastrophic

COPIES TO: STRUCTURAL ___ MECHANICAL ___ MATERIALS ___ GSE ___ OTHER ___

AVIONICS ___ PROPULSION ___ VEHICLE SUPPORT ___ FACILITIES ___ PAYLOAD ___ SYS SAFETY X

ACTION RECOMMENDED: Implement rigid controls on fabrication, inspection and installation of fuel lines to prohibit the installation of incipient defects. Insure that adequate protection of the lines during servicing and maintenance operations. Provide an inert gas purge of cargo bay while on the pad that will continue to inert cargo bay on ascent.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				Marginal

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED ______

INTEGRATION

HAZARD ANALYSIS

DATE ______

REV ______

END ITEM Shuttle Booster	SUBSYSTEM Propellant Tank Pressurization	SUBSYSTEM IDENT NO. 13
OPERATION/PHASE Launch - Perform initial ascent maneuver		OP. IDENT. NO. B
HAZARD GROUP Fire/Explosion, Loss of thrust, contamination		HAZARD GRP. CODE 1,7
REFERENCES FMEA 2.6.1		AUTHORITY Project II, Task II-3

HAZARD DESCRIPTION/ EFFECTS Failure of the stage-mounted flow control device in the closed position, due to contamination, could prevent required pressure head to the engine pumps. This could also be a result of failure in the sensed ullage pressure sensor. The effect of this hazard is loss of engine thrust resulting in abort. Reduction in Hydrogen flow could cause oxygen-rich combustion which may cause burnout of the engine resulting in fire or explosion.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			Catastrophic

COPIES TO: STRUCTURAL ___ MECHANICAL ___ MATERIALS ___ GSE ___ OTHER ___

AVIONICS ___ PROPULSION ___ VEHICLE SUPPORT ___ FACILITIES ___ PAYLOAD ___ SYS SAFETY X

ACTION RECOMMENDED:

Maintain strict controls to prevent entry of all forms of contamination. Provide redundant pressure sensing and control. Provide filters upstream of critical components.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				Marginal

9

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED ______

INTEGRATION

HAZARD ANALYSIS

PAGE 1 OF 1

DATE ______

REV ______

END ITEM Shuttle Orbiter	SUBSYSTEM Propellant Tank Insulation	SUBSYSTEM IDENT NO. 6
OPERATION/PHASE Launch/Ascent - Perform initial ascent maneuver		OP. IDENT. NO. B
HAZARD GROUP Loss of thrust		HAZARD GRP. CODE 7
REFERENCES FMEA 2.6.1		AUTHORITY Task II-3

HAZARD DESCRIPTION/ EFFECTS Internal insulation of the LH_2 tanks if not contained properly can crack, peel and flake, clogging the propulsion system causing improper mixture to the engines, resulting in hot spots, burn-through and fire or explosion. Loss of thrust on both engines requires abort, using the OMS engines. An explosion in the engine compartment may destroy the capability to abort safely.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			Critical

COPIES TO: STRUCTURAL ___ MECHANICAL ___ MATERIALS ___ GSE ___ OTHER ___

AVIONICS ___ PROPULSION ___ VEHICLE SUPPORT ___ FACILITIES ___ PAYLOAD ___ SYS SAFETY X

ACTION RECOMMENDED:

Insure an adequate development program to provide an internal insulation that is least likely to deteriorate. Provide screens on fuel lines to block particles that could damage engines.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				Marginal

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED ______

HAZARD ANALYSIS

PAGE ____ OF ____
DATE ______
REV ______

END ITEM Shuttle Orbiter	SUBSYSTEM Pressurization	SUBSYSTEM IDENT NO. 13
OPERATION/PHASE Launch/Ascent - Perform initial ascent maneuver		OP. IDENT. NO. B
HAZARD GROUP Explosion, Loss of thrust		HAZARD GRP. CODE 1, 7
REFERENCES FMEA 2.6.1		AUTHORITY Task II-3

HAZARD DESCRIPTION/ EFFECTS The loss of a Helium tank due to rupture will subject the vehicle to an explosive blast and fragmentation. The effect of this rupture could cause loss of one main engine, and if the tank location is close to the pressure hull, fragmentation could destroy the integrity of the ECLSS. Depending on the H_e bottle location, blast and fragmentation could destroy the capability for safe abort. This hazard could be created by defective material, poor workmanship, stress concentration, corrosion, excessive cycling of pressurization or vibration fatigue.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			Critical

COPIES TO: STRUCTURAL ____ MECHANICAL ____ MATERIALS ____ GSE ____ OTHER ____

AVIONICS ____ PROPULSION ____ VEHICLE SUPPORT ____ FACILITIES ____ PAYLOAD ____ SYS SAFETY X

ACTION RECOMMENDED: Insure adequate development of H_e tank to minimize chance of rupture. This development should include a proof-pressure test to 1-1/2 times working pressure. Provide scatter shields to minimize damage from fragments. Provide pressure relief to minimize over-pressurization.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				Marginal

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED

INTEGRATION

HAZARD ANALYSIS

DATE

REV

END ITEM
Shuttle Orbiter

SUBSYSTEM Pressurization

SUBSYSTEM IDENT NO.
13

OPERATION/PHASE
Launch/Ascent - Perform initial ascent maneuver

OP. IDENT. NO.
B

HAZARD GROUP
Explosion, loss of thrust

HAZARD GRP. CODE
1, 7

REFERENCES FMEA 2.6.1

AUTHORITY

HAZARD DESCRIPTION/ EFFECTS

The loss of the accumulator or feed lines, due to rupture, to the main engines can produce a blast hazard and fragmentation. The effect of this hazard is loss of engine thrust requiring abort.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			Critical

COPIES TO: STRUCTURAL ___ MECHANICAL ___ MATERIALS ___ GSE ___ OTHER ___

AVIONICS ___ PROPULSION ___ VEHICLE SUPPORT ___ FACILITIES ___ PAYLOAD ___ SYS SAFETY X

ACTION RECOMMENDED:

Proof-test accumulator or feed lines to pressures greater than those to which the components will be exposed in service. (Max. operating pressure X 1.5 (hydrostat) or max. operating pressure x 1.25 for pneumostat).

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				Marginal

12

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED

OPERATIONAL HAZARD ANALYSIS

DATE

REV

END ITEM Shuttle Orbiter	SUBSYSTEM Avionics	SUBSYSTEM IDENT NO. 1
OPERATION/PHASE Orbital - perform rendezvous		OP. IDENT. NO. C
HAZARD GROUP Fire/Explosion, Impact		HAZARD GRP. CODE 1, 8
REFERENCES FMEA 3.1 FMEA 4.2 FMEA 5.2		AUTHORITY Project II, Task II-3

HAZARD DESCRIPTION/ EFFECTS During the rendezvous maneuver loss of approach radar or communication would create a hazard which could lead to catastrophic consequences through impact with the passive target. The effect would be possible structural failure initiating the mechanism for fire or explosion of the propellant tankage in the cargo bay. Damage to the docking section structure or structural failure of the pressure hull of the orbiter are potential effects. While the target may be visually located, lack of target illumination would render visibility a factor in the accident.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			Catastrophic

COPIES TO: STRUCTURAL ___ MECHANICAL ___ MATERIALS ___ GSE ___ OTHER ___

AVIONICS ___ PROPULSION ___ VEHICLE SUPPORT ___ FACILITIES ___ PAYLOAD ___ SYS SAFETY X

ACTION RECOMMENDED: Provide alternate capability in critical radar and communications equipment that is automatically initiated when the primary mode fails, or warning indications when the capability to make a safe rendezvous maneuver is marginal or lost.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				Marginal

13

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED

OPERATIONAL

HAZARD ANALYSIS

PAGE 1 OF 1

DATE

REV

END ITEM Shuttle Orbiter	**SUBSYSTEM** Structural	**SUBSYSTEM IDENT NO.** 5
OPERATION/PHASE Orbital - Perform rendezvous		**OP. IDENT. NO.** C
HAZARD GROUP Impact, Fire/explosion		**HAZARD GRP. CODE** 8, 1
REFERENCES FMEA 3.1, Ref. 29 FMEA 4.2, FMEA 5.2		**AUTHORITY** Project II, Task II-3

HAZARD DESCRIPTION/ EFFECTS The hazard by impact of a meteoroid in critical areas is an inherent hazard to space operations. The magnitude of the hazard will depend on the size of the meteoroid and the effectiveness of the meteoroid shield. Meteoroids in excess of 1 gm mass and 15 mm diameter may be expected to penetrate the structure, release energy within the structure and damage equipment or start fires in local areas. The penetration hole will cause loss of pressure in the pressure hull which if not repaired within the allowable timeline will cause loss of the habitable environment.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			Catastrophic

COPIES TO: STRUCTURAL ___ MECHANICAL ___ MATERIALS ___ GSE ___ OTHER ___

AVIONICS ___ PROPULSION ___ VEHICLE SUPPORT ___ FACILITIES ___ PAYLOAD ___ SYS SAFETY X

ACTION RECOMMENDED: Meteoroid shield should be designed to resist impact of 1 gram mass and smaller. For impact of larger masses crew should be provided a second habitable environment (suit or compartment) that will sustain life until repairs are made or crew is rescued. Provisions shall be made for repair or temporary plugging of damage resulting from meteoroids until permanent structural soundness can be restored.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				Critical

14

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED ______

OPERATIONAL HAZARD ANALYSIS

PAGE 1 OF 1
DATE ______
REV ______

END ITEM: Shuttle Orbiter	SUBSYSTEM: Structural	SUBSYSTEM IDENT NO.: 5
OPERATION/PHASE: Orbital - perform rendezvous		OP. IDENT. NO.: C
HAZARD GROUP: Impact		HAZARD GRP. CODE: 8
REFERENCES: FMEA 3.1 FMEA 4.2 FMEA 5.2		AUTHORITY: Task II-3

HAZARD DESCRIPTION/ EFFECTS Debris in space could impact the orbiter with catastrophic results through failure to detect the debris in the flight path or on an intercept course. This hazard could result in structural damage. Debris can range from particulate matter to complete vehicles. The effects of impact are manifest in the structural damage inflicted, location of the damage relative to critical systems and severity of penetration of the ECLSS.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			Catastrophic

COPIES TO: STRUCTURAL ___ MECHANICAL ___ MATERIALS ___ GSE ___ OTHER ___

AVIONICS ___ PROPULSION ___ VEHICLE SUPPORT ___ FACILITIES ___ PAYLOAD ___ SYS SAFETY X

ACTION RECOMMENDED: Launches should be timed to miss the space debris detectable by ground-based radar. Orbiter surveillance radar should have redundant capability for detection of smaller debris so that this can be avoided by maneuvering orbiter. Ground tracking systems should work in unison with shuttle orbiter systems to locate space debris and program flight paths in an area where no debris exists.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				Marginal

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED ______

OPERATIONAL
HAZARD ANALYSIS

PAGE ____ OF ____
DATE ______
REV ______

END ITEM Shuttle Orbiter/LSF	SUBSYSTEM Avionics	SUBSYSTEM IDENT NO. 1
OPERATION/PHASE Orbital - perform rendezvous		OP. IDENT. NO. C
HAZARD GROUP Impact, fire/explosion		HAZARD GRP. CODE 1, 8
REFERENCES FMEA 3.1 FMEA 4.2 FMEA 5.2		AUTHORITY Project II, Task II-3

HAZARD DESCRIPTION/ EFFECTS Loss of command communications through failure of the data up/down link introduces a hazard represented by loss of tracking and ranging signals from MSFN. The hazard may be marginal to catastrophic depending on the proximity of the LSF to the orbiter and ability to track the LSF. The extreme hazard would be misjudgement of the relative velocity between the passive target (LSF) and the orbiter. Effects of this situation could cause impact of the vehicles with a high potential of fire or explosion.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			Catastrophic

COPIES TO: STRUCTURAL ____ MECHANICAL ____ MATERIALS ____ GSE ____ OTHER ____

AVIONICS ____ PROPULSION ____ VEHICLE SUPPORT ____ FACILITIES ____ PAYLOAD ____ SYS SAFETY X

ACTION RECOMMENDED:

Provide alternate capability in critical communication links that is automatically initiated should the primary mode fail. The crew should be alerted to the failure of the primary mode so that repairs can be made.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				Marginal

16

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED

OPERATIONAL HAZARD ANALYSIS

PAGE ____ OF ____
DATE ____
REV ____

END ITEM Shuttle Orbiter	SUBSYSTEM Propulsion	SUBSYSTEM IDENT NO. 2
OPERATION/PHASE Orbital - perform rendezvous		OP. IDENT. NO. C
HAZARD GROUP Loss of attitude control		HAZARD GRP. CODE 9
REFERENCES FMEA 3.1 FMEA 4.2 FMEA 5.2		AUTHORITY Project II, Task II-3

HAZARD DESCRIPTION/ EFFECTS The loss of attitude control of the orbiter renders the mission lost as rendezvous cannot be achieved in a stabilized condition. This instability may cause disturbances which are associated with sloshing of propellants. The hazard can become catastrophic should the decision be made to attempt to dock with the target and again when attitude control cannot be maintained for re-entry. In the first case the hazard is associated with impact, while the latter case is related to vehicle attitude.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			Catastrophic

COPIES TO: STRUCTURAL ____ MECHANICAL ____ MATERIALS ____ GSE ____ OTHER ____

AVIONICS ____ PROPULSION ____ VEHICLE SUPPORT ____ FACILITIES ____ PAYLOAD ____ SYS SAFETY X

ACTION RECOMMENDED:

RCS controls should have back-up capability to provide attitude control in case the primary mode fails. Prohibit by operational control attempts to dock with an unstable vehicle.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				Marginal

17

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED

OPERATIONAL

HAZARD ANALYSIS

PAGE ____ OF ____

DATE ____

REV ____

END ITEM Shuttle Orbiter	SUBSYSTEM Vehicle Support - Electrical	SUBSYSTEM IDENT NO. 3
OPERATION/PHASE Orbital - perform rendezvous		OP. IDENT. NO. C
HAZARD GROUP Reduced integrity of structure or equipment		HAZARD GRP. CODE 2
REFERENCES FMEA 3.1 FMEA 4.2		AUTHORITY Project II, Task II-3

HAZARD DESCRIPTION/ EFFECTS A control system malfunction affecting the fuel cells could cause loss of all electrical power. The orbiter has two nickel-cadmium batteries as backup for use in reset and restart of the fuel cells or APU. The hazard is the potential inability of the crew to restart the fuel cells due to the system malfunction. This loss of capability to reactivate the electrical system could result in loss of the mission with the subsequent loss of the crew.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			Catastrophic

COPIES TO: STRUCTURAL ____ MECHANICAL ____ MATERIALS ____ GSE ____ OTHER ____

AVIONICS ____ PROPULSION ____ VEHICLE SUPPORT ____ FACILITIES ____ PAYLOAD ____ SYS SAFETY X

ACTION RECOMMENDED:

The fuel cell controls should be provided with multiple capability to insure restart.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				Marginal

18

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED ______

INTEGRATION

HAZARD ANALYSIS

PAGE ____ OF ____
DATE ______
REV ______

END ITEM Orbiter	SUBSYSTEM Vehicle Support - ECLSS	SUBSYSTEM IDENT NO. 3
OPERATION/PHASE Orbital - Perform rendezvous		OP. IDENT. NO. C
HAZARD GROUP Heat/Temperature		HAZARD GRP. CODE 6
REFERENCES FMEA 3.1 FMEA 4.2		AUTHORITY Project II, Task II-3

HAZARD DESCRIPTION/ EFFECTS The loss of functional efficiency of the orbital heat rejection radiator in the orbiter cargo bay doors, due to inability to open the doors to the desired position, can cause a hazard imposed by inability to dissipate heat from the radiator. This could possibly overload the sublimator if used as the primary heat rejection source. The hazard would affect systems dependent on this system for their cooling capability.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			Critical[1]

COPIES TO: STRUCTURAL ___ MECHANICAL ___ MATERIALS ___ GSE ___ OTHER ___

AVIONICS ___ PROPULSION ___ VEHICLE SUPPORT ___ FACILITIES ___ PAYLOAD ___ SYS SAFETY X

ACTION RECOMMENDED: Cargo bay doors should be provided with more than one means of openings. In case of failure of the primary means, it should be capable of being de-energized to permit secondary means to operate. Mechanical means should be provided to release the doors from primary system and manual means to open doors.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				Marginal

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED

OPERATIONAL
HAZARD ANALYSIS

PAGE ____ OF ____
DATE ____
REV ____

END ITEM	SUBSYSTEM	SUBSYSTEM IDENT NO.
Shuttle Orbiter	Propulsion - OMS	2

OPERATION/PHASE: Orbital - Perform rendezvous

OP. IDENT. NO.: C

HAZARD GROUP: Impact

HAZARD GRP. CODE: 8

REFERENCES: FMEA 3.1 FMEA 4.2 FMEA 5.2

AUTHORITY:

HAZARD DESCRIPTION/ EFFECTS The increase in ΔV caused by failure or delay in closing the LH_2/LOX supply prevalves could create a potential hazard if not detected by the crew. The results could cause an improper catchup procedure to be executed which could cause impact of the orbiter with the passive target. Evasive action may be involved in this impact which could lead to hull penetration.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			Catastrophic

COPIES TO: STRUCTURAL ____ MECHANICAL ____ MATERIALS ____ GSE ____ OTHER ____

AVIONICS ____ PROPULSION ____ VEHICLE SUPPORT ____ FACILITIES ____ PAYLOAD ____ SYS SAFETY X

ACTION RECOMMENDED: Provide automatic capability of approach and guidance during catch-up maneuver with alarm and manual over-ride should automatic capability fail. Provide back-up capability to terminate propellant flow.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				Marginal

20

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED ____

OPERATIONAL HAZARD ANALYSIS

PAGE ____ OF ____
DATE ____
REV ____

END ITEM Orbiter Shuttle / SUBSYSTEM Avionics/Human	SUBSYSTEM IDENT NO. 1, 12
OPERATION/PHASE Orbital - Maneuver to emplace payload/ equipment or LO_2 module	OP. IDENT. NO. C
HAZARD GROUP Impact	HAZARD GRP. CODE 8
REFERENCES FMEA 3.2 FMEA 5.2	AUTHORITY Project II, Task II-3

HAZARD DESCRIPTION/ EFFECTS Improper procedures, restricted vision, and malfunctioning docking aids could cause the orbiter to impact the passive target with a force exceeding the allowable docking design, or at an angle which could damage the insulation of the target. In the event the impact was taken on the pressure hull, the hull may loose its capability to maintain the compartment habitable environment.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			Critical

COPIES TO: STRUCTURAL ____ MECHANICAL ____ MATERIALS ____ GSE ____ OTHER ____

AVIONICS ____ PROPULSION ____ VEHICLE SUPPORT ____ FACILITIES ____ PAYLOAD ____ SYS SAFETY X

ACTION RECOMMENDED: The operating crew should be trained on simulators that closely approximate actual docking conditions. Procedures should be implemented to prohibit attempts to dock if critical docking aids are not available.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				Marginal

21

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED ______

OPERATIONAL

HAZARD ANALYSIS

PAGE ____ OF ____

DATE ______

REV ______

END ITEM Orbiter	SUBSYSTEM Propulsion	SUBSYSTEM IDENT NO. 2
OPERATION/PHASE Orbital - Maneuver to emplace payload/ propellant or LO_2 module		OP. IDENT. NO. C
HAZARD GROUP Impact		HAZARD GRP. CODE 8
REFERENCES FMEA 3.2 FMEA 5.3		AUTHORITY Project II, Task II-3

HAZARD DESCRIPTION/ EFFECTS During maneuvering of the orbiter to emplace a payload, inadvertent or miss-operation of the propulsive vent system could empart an undesired ΔV to the orbiter in such a manner as to cause impact of the orbiter with the passive target. This condition could possibly exist if the crew could not isolate the venting and take corrective action or if the propulsive vent valve was failed in the open condition due to contamination. Under certain line configured conditions (valves in the propellant distribution system open) the pressure in the GH_2 and GO_2 accumulators could be lost.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			Critical

COPIES TO: STRUCTURAL ____ MECHANICAL ____ MATERIALS ____ GSE ____ OTHER ____

AVIONICS ____ PROPULSION ____ VEHICLE SUPPORT ____ FACILITIES ____ PAYLOAD ____ SYS SAFETY X

ACTION RECOMMENDED:

Maintain procedural controls to prevent contamination. Provide filters in actuation lines for critical valves. Provide RCS capability to correct for inadvertent propulsive venting.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				Marginal

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED ______

OPERATIONAL

HAZARD ANALYSIS

PAGE ____ OF ____
DATE ______
REV ______

END ITEM Shuttle Orbiter	SUBSYSTEM Vehicle Support-Manipulator	SUBSYSTEM IDENT NO. 3
OPERATION/PHASE	Orbital - Deploy payload, LO_2 and equipment or crew module/dock	OP. IDENT. NO. C
HAZARD GROUP	Reduced integrity of structure or equipment	HAZARD GRP. CODE 2
REFERENCES	FMEA 3.3 FMEA 4.3 FMEA 5.5, 5.10, 6.1	AUTHORITY Project II, Task II-3

HAZARD DESCRIPTION/ EFFECTS A hazard is created in the situation where the payload has been deployed and the orbiter manipulators fail in an intermediate position through failure of the system. The hazard relates to inability to configure the orbiter for return to earth in that the cargo bay doors cannot be closed with the payload partially deployed. EVA by the crew may allow repair of the system covering only mission delay; however, if the manipulator or payload or both cannot be disposed of in a manner such as to allow release from the orbiter, the mission could be lost on re-entry.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			Critical

COPIES TO: STRUCTURAL ____ MECHANICAL ____ MATERIALS ____ GSE ____ OTHER ____

AVIONICS ____ PROPULSION ____ VEHICLE SUPPORT ____ FACILITIES ____ PAYLOAD ____ SYS SAFETY X

ACTION RECOMMENDED:

The manipulators should be designed so that they can be removed and jettisoned in space when they become incapable of being stowed.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				Marginal

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED ______

OPERATIONAL

HAZARD ANALYSIS

PAGE ____ OF ____

DATE ______

REV ______

END ITEM Shuttle Orbiter	SUBSYSTEM Vehicle Support - Manipulators	SUBSYSTEM IDENT NO. 3
OPERATION/PHASE Orbital - Deploy payload, LO_2 and equipment or crew module/dock		OP. IDENT. NO. C
HAZARD GROUP Impact, loss of attitude control		HAZARD GRP. CODE 8,9
REFERENCES FMEA 3.3 FMEA 4.3 FMEA 5.5 FMEA 5.10 FMEA 6.1		AUTHORITY Project II, Task II-3

HAZARD DESCRIPTION/ EFFECTS Failure in the manipulator control could cause overcontrol to occur where an extra velocity is imparted to the payload or where the system bottoms out with no decrease in payload velocity. Since the orbiter will react to the sudden stoppage of the payload, disturbances can be imparted into the orbiter which may affect the crew, and attitude of the orbiter, due in part to the stored energy in the manipulator arms and partially to the sloshing of propellants. During this condition it could be expected that impact between the payload and passive target could also occur, causing vehicle damage.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			Critical

COPIES TO: STRUCTURAL ____ MECHANICAL ____ MATERIALS ____ GSE ____ OTHER ____

AVIONICS ____ PROPULSION ____ VEHICLE SUPPORT ____ FACILITIES ____ PAYLOAD ____ SYS SAFETY X

ACTION RECOMMENDED:

Limiting devices should be incorporated in the manipulator system to limit to a safe level the energy that could be imparted by the manipulators.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				Marginal

24

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED ______

INTEGRATION
HAZARD ANALYSIS

PAGE ____ OF ____
DATE ______
REV ______

END ITEM Shuttle Orbiter/LSF	SUBSYSTEM Vehicle Support - Manipulator	SUBSYSTEM IDENT NO. 3
OPERATION/PHASE Orbital - Deploy payload, LO_2 and equipment or crew module/dock		OP. IDENT. NO. C
HAZARD GROUP Impact		HAZARD GRP. CODE 8
REFERENCES FMEA 3.3, 4.3, 4.4, 5.5, 5.9, 5.10, 6.1		AUTHORITY Project II - Task II-3

HAZARD DESCRIPTION/ EFFECTS The manipulators have installed TV cameras and floodlights on the manipulator arms so that the control operator can observe the action of the arms in relation to the load. Failure of these items could create an impact hazard if the failure occurred in the timeline of emplacement of the payload. This presupposes the operator is not provided sufficient time to prevent impact, by system shutdown. The control operator has a canopy from which he operates the manipulators. Failure or inadvertent operation of the fairing door over the canopy could cause the loss of any visual reference if the fairing doors moved to the closed or partial open condition. This again, depending on the operational condition, could create an impact hazard.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			Critical

COPIES TO: STRUCTURAL ____ MECHANICAL ____ MATERIALS ____ GSE ____ OTHER ____

AVIONICS ____ PROPULSION ____ VEHICLE SUPPORT ____ FACILITIES ____ PAYLOAD ____ SYS SAFETY X

ACTION RECOMMENDED:

Operational procedures and training should be implemented to safely stop manipulator operations if the operator loses contact with load or target.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				Marginal

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED ______

INTERFACE

HAZARD ANALYSIS

PAGE ____ OF ____

DATE ______

REV ______

END ITEM Shuttle Orbiter	SUBSYSTEM Mechanical	SUBSYSTEM IDENT NO. 4
OPERATION/PHASE	Orbital - Deploy payload, LO_2 and equipment or crew module/dock	OP. IDENT. NO. C
HAZARD GROUP Loss of habitable environment		HAZARD GRP. CODE 10
REFERENCES FMEA 3.3, 4.4, 5.3, 5.9		AUTHORITY Project II, Task II-3

HAZARD DESCRIPTION/ EFFECTS Failure of the docking ring to latch introduces the hazard of loss of internal pressure (habitable environment) through leakage past the docking ring seals. The failure to latch also could impact the capability to rigidize the docking hatch thus causing delay in personnel transfer to the crew or equipment module. The hazard would affect the docking operation only if undetected by the crew when in the unsuited mode. In this case the extreme result would be loss of habitable environment.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			Critical

COPIES TO: STRUCTURAL ____ MECHANICAL ____ MATERIALS ____ GSE ____ OTHER ____

AVIONICS ____ PROPULSION ____ VEHICLE SUPPORT ____ FACILITIES ____ PAYLOAD ____ SYS SAFETY X

ACTION RECOMMENDED: Means should be provided to determine the environmental conditions on both sides of a man-way door prior to opening the door. If the conditions are unsafe on the other side of the door the door should not be opened.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				Negligible

26

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED ______

OPERATIONAL HAZARD ANALYSIS

PAGE ____ OF ____

DATE ______

REV ______

END ITEM Shuttle Orbiter/LSF	SUBSYSTEM Structural	SUBSYSTEM IDENT NO. 5
OPERATION/PHASE Orbital - Deploy payload, LO_2 and equipment or crew module/dock		OP. IDENT. NO. C
HAZARD GROUP Impact		HAZARD GRP. CODE 8
REFERENCES FMEA 3.3, 5.5		AUTHORITY Project II, Task II-3

HAZARD DESCRIPTION/ EFFECTS An undesired ΔV from the orbiter RCS or propulsive vents during docking could create an impact hazard. This hazard could result in damage to the docking ring, insulation damage, damage to the orbiter by causing hatchway sealing surfaces to part, or if impact occurs at an angle, the line interconnect fixture could be **damaged, or propellant tank module ruptured. These hazards** are time dependent and operationally oriented. Corrective action could be taken by the crew if time permitted.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			Critical

COPIES TO: STRUCTURAL ____ MECHANICAL ____ MATERIALS ____ GSE ____ OTHER ____

AVIONICS ____ PROPULSION ____ VEHICLE SUPPORT ____ FACILITIES ____ PAYLOAD ____ SYS SAFETY X

ACTION RECOMMENDED: The RCS should be designed to correct inadvertent propulsive venting. RCS controls should have back-up capability in case of the failure of the primary mode.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				Marginal

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED ______

INTEGRATION

HAZARD ANALYSIS

PAGE ____ OF ____

DATE ______

REV ______

END ITEM Shuttle Orbiter/LSF	SUBSYSTEM Avionics	SUBSYSTEM IDENT NO. 1
OPERATION/PHASE D Orbital - (Deploy payload, LO_2 and equipment (or crew module/dock		OP. IDENT. NO. C
HAZARD GROUP Loss of Communication		HAZARD GRP. CODE 11
REFERENCES FMEA 3.3		AUTHORITY Task II-3

HAZARD DESCRIPTION/ EFFECTS Electrical/electronics failures which render the communication system inoperative between crew members during the critical period of deployment and docking introduces a hazard of blackout which if dependent on a coordinated crew effort could cause operational problems. These problems are associated with a configuration which has a payload deployed prior to the docking function being completed. The hazard is minor if operational procedures require crew station verification of all execute commands.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			Marginal

COPIES TO: STRUCTURAL ____ MECHANICAL ____ MATERIALS ____ GSE ____ OTHER ____

AVIONICS ____ PROPULSION ____ VEHICLE SUPPORT ____ FACILITIES ____ PAYLOAD ____ SYS SAFETY X

ACTION RECOMMENDED: Critical communications should have redundant capability. If communications are interrupted while docking, back-out procedures should be implemented to safely terminate the operations until repairs can be made.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				Negligible

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED ______

OPERATIONAL

HAZARD ANALYSIS

PAGE ____ OF ____

DATE ______

REV ______

END ITEM Shuttle Orbiter/LSF

SUBSYSTEM Mechanical

SUBSYSTEM IDENT NO. 4

OPERATION/PHASE Orbital - Dock with orbiting body

OP. IDENT. NO. C

HAZARD GROUP Disturbances

HAZARD GRP. CODE 12

REFERENCES FMEA 3.3, 4.4

AUTHORITY Task II-3

HAZARD DESCRIPTION/ EFFECTS In docking with the LSF, misalignment between the axis of the adapter and shuttle docking port, greater than a 7° angle, could establish the conditions where a capture latch could engage the docking ring. A hazard is created when, due to misalignment, undocking is attempted for another approach to dock. The hazard is the disturbances which can be imparted into the orbiter if the undocking movement hangs up at the latch, but through a slight rotation around the axis causes the lock to become disengaged. The lock plus RCS action could cause propellant sloshing which upon release from the latch could create undesired disturbances.

ORIGINATOR | **GROUP** | **EXT.** | **HAZARD CLASS** Critical

COPIES TO: STRUCTURAL ___ MECHANICAL ___ MATERIALS ___ GSE ___ OTHER ___

AVIONICS ___ PROPULSION ___ VEHICLE SUPPORT ___ FACILITIES ___ PAYLOAD ___ SYS SAFETY X

ACTION RECOMMENDED: Automatic corrective action with manual override should be initiated if the angular deviation is exceeded during docking. Procedural controls should be implemented to prevent attempts to undock with latch engaged. Provide back-up release mechanism.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				Marginal

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED ______

OPERATIONAL HAZARD ANALYSIS

PAGE ____ OF ____
DATE ______
REV ______

END ITEM Orbiter/LSF	SUBSYSTEM Avionics/Human	SUBSYSTEM IDENT NO. 1, 12
OPERATION/PHASE Orbital - Dock with orbiting body		OP. IDENT. NO. C
HAZARD GROUP Impact		HAZARD GRP. CODE 8
REFERENCES FMEA 3.3, 4.4, 5.5, 5.9		AUTHORITY Project II, Task II-3

HAZARD DESCRIPTION/ EFFECTS In the process of docking to the passive vehicle, if an erroneous command is introduced into the stabilization system via ground net or orbiter, the unstabilizing affect could cause impact between the vehicles. The magnitude of the hazard is a function of the detection and correction time, distance between vehicles, magnitude of the unstabilizing thrust, and amount of coupling between propellant slosh and vehicle. The signal for the erroneous command could be by failure in the avionics system or could be human induced.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS Critical

COPIES TO: STRUCTURAL ____ MECHANICAL ____ MATERIALS ____ GSE ____ OTHER ____

AVIONICS ____ PROPULSION ____ VEHICLE SUPPORT ____ FACILITIES ____ PAYLOAD ____ SYS SAFETY X

ACTION RECOMMENDED: Automatic corrective action with manual override should be implemented if the approach velocity or angular deviation exceeds critical limits while docking. Stabilization controls should have back-up capability in case of failure of the primary systems.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				Marginal

30

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED ______

OPERATIONAL
HAZARD ANALYSIS

PAGE ____ OF ____
DATE ______
REV ______

END ITEM Orbiter/RNS/CIS Supportive SII Derivative LSF	SUBSYSTEM Avionics	SUBSYSTEM IDENT NO. 1
OPERATION/PHASE Orbital - Activate selected systems		OP. IDENT. NO. C
HAZARD GROUP Loss of communication		HAZARD GRP. CODE 11
REFERENCES FMEA 3.4, 5.5		AUTHORITY Project II, Task II-3

HAZARD DESCRIPTION/ EFFECTS Loss of communication between the ground net or shuttle and the LSF could be caused by failure of avionics components located outside of the LSF structure. In order to activate the subsystems EVA repair may be required. Hazards to the crew are directly related to the extent and duration of the required EVA effort, and could be associated with fouling of life support oxygen supply line, penetration of the EVA suit by sharp objects or meteoroid, loss of grip or restraint during the work operation, sun blindness, fatigue, and impact of space debris.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			Critical

COPIES TO: STRUCTURAL ____ MECHANICAL ____ MATERIALS ____ GSE ____ OTHER ____

AVIONICS ____ PROPULSION ____ VEHICLE SUPPORT ____ FACILITIES ____ PAYLOAD ____ SYS SAFETY X

ACTION RECOMMENDED: EVA should be limited to mandatory requirements and only then after the crewman is fully trained to recognize and prevent operational hazard affects. Sharp corners and undesired restrictions in the use of the EVA suit should be eliminated in the design. EVA is a high risk operation and some hazard effects, such as meteoroid impact will have **serious results.**

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				Critical

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED ______

OPERATIONAL
HAZARD ANALYSIS

PAGE ____ OF ____
DATE ______
REV ______

END ITEM LSF/Equipment Module	SUBSYSTEM Structural	SUBSYSTEM IDENT NO. 5
OPERATION/PHASE Orbital - Activate selected subsystems		OP. IDENT. NO. C
HAZARD GROUP Loss of habitable environment		HAZARD GRP. CODE 10
REFERENCES FMEA 3.4, 5.5		AUTHORITY Task II-3

HAZARD DESCRIPTION/ EFFECTS Hard docking of the equipment module may damage the airlock seal to the crew compartment. Damage would introduce the hazard of loss of a habitable environment and cause rapid expenditure of the ECLSS fluids. This hazard to the crew is non-existent where the operational requirement exists for IVA suit use during the operation, emergency LSS are provided and/or rapid return to the orbiter is achievable.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			Marginal

COPIES TO: STRUCTURAL ____ MECHANICAL ____ MATERIALS ____ GSE ____ OTHER ____

AVIONICS ____ PROPULSION ____ VEHICLE SUPPORT ____ FACILITIES ____ PAYLOAD ____ SYS SAFETY X

ACTION RECOMMENDED: To prevent docking damage the approach should incorporate automatic corrective action when the approach velocity or angular deviation exceeds critical limits. When docking to manned modules the crewmen should be suited to provide a redundant ECLSS volume.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				Negligible

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED ______

INTEGRATION

HAZARD ANALYSIS

PAGE ____ OF ____

DATE ______

REV ______

END ITEM Equipment/Crew Module/LSF — SUBSYSTEM Vehicle Support - EC/LSS	SUBSYSTEM IDENT NO. 3
OPERATION/PHASE Orbital - Activate Selected Subsystems	OP. IDENT. NO. C
HAZARD GROUP Loss of habitable environment	HAZARD GRP. CODE 10
REFERENCES FMEA 3.4	AUTHORITY Project II, Task II-3

HAZARD DESCRIPTION/ EFFECTS The crew module and crew compartment of the equipment module together with the passageway connecting the modules is maintained in a shirtsleeve environment by the EC/LSS which draws on the oxygen supply from the LOX module. An electromechanical failure in this supply system, which precludes oxygen flow, renders the system inoperative. Should the atmosphere flow rate drop below nominal, another condition is created which causes hazards due to heat buildup, water vapor, increased levels of carbon dioxide and trace contaminates which renders the area uninhabitable (except in a suited condition).

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			Critical

COPIES TO: STRUCTURAL ____ MECHANICAL ____ MATERIALS ____ GSE ____ OTHER ____

AVIONICS ____ PROPULSION ____ VEHICLE SUPPORT ____ FACILITIES ____ PAYLOAD ____ SYS SAFETY X

ACTION RECOMMENDED: Critical EC/LSS components should have back-up capability in case the primary mode fails to provide LSS until rescue can be effected. Hazard alarms should be incorporated to alert crew of hazardous concentration.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				Marginal

33

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED ______

INTEGRATION

HAZARD ANALYSIS

PAGE ____ OF ____

DATE ______

REV ______

END ITEM Equipment/Crew Module LSF	SUBSYSTEM Mechanical	SUBSYSTEM IDENT NO. 4
OPERATION/PHASE Orbital - Perform final checkout of subsystem		OP. IDENT. NO. C
HAZARD GROUP Loss of habitable environment		HAZARD GRP. CODE 10
REFERENCES FMEA 3.5		AUTHORITY Project II, Task II-3

HAZARD DESCRIPTION/ EFFECTS Leakage which could occur at line connections or welds within the equipment module line routing tunnel or in the area of the line interconnect fixture, could present a hazard due to confinement of the gasses, leading to explosion, or damaging the crew station area or the storage area between the crew station and airlock. Such damage could contaminate the crew station tunnel way between the equipment and crew module or restrict entry to the airlock without EVA suits. A mass rupture of the lines may cause loss of crew.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			Critical

COPIES TO: STRUCTURAL ____ MECHANICAL ____ MATERIALS ____ GSE ____ OTHER ____

AVIONICS ____ PROPULSION ____ VEHICLE SUPPORT ____ FACILITIES ____ PAYLOAD ____ SYS SAFETY X

ACTION RECOMMENDED: The number of leak points in the line routing should be minimized in the design. The remaining joints should have permanent connections to minimize leakage. Live connections should be leak-checked prior to initiating propellant flow. The ability to monitor, detect or initiate an alarm system in crew quarters should be designed into the design of the piping system for all connections subject to leakage.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				Marginal

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED ______

INTERFACE

HAZARD ANALYSIS

PAGE ____ OF ____
DATE ______
REV ______

END ITEM Equipment Module	SUBSYSTEM Avionics	SUBSYSTEM IDENT NO. 1
OPERATION/PHASE Orbital - Perform final checkout of subsystems		OP. IDENT. NO. C
HAZARD GROUP Fire, contamination		HAZARD GRP. CODE 1,3
REFERENCES FMEA 3.5		AUTHORITY Project II, Task II-3

HAZARD DESCRIPTION/ EFFECTS Electrical lines which are mismated or grounded improperly and cause arcing or high current draw, produce an electrical overload which could cause welding of contact points, potential fires and contamination due to burning insulation. Depending on the status of the electrical configuration these hazards could cause loss of the system requiring return of the module to earth base. The environmental contamination would require personnel evacuation until a habitable environment was available.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			Critical

COPIES TO: STRUCTURAL ____ MECHANICAL ____ MATERIALS ____ GSE ____ OTHER ____

AVIONICS ____ PROPULSION ____ VEHICLE SUPPORT ____ FACILITIES ____ PAYLOAD ____ SYS SAFETY X

ACTION RECOMMENDED: Electrical connectors that require detachment and re-engagement during servicing or use must be simply and positively identified to prevent insertion errors. Adjacent connectors should be configured differently to prevent mis-connection. Training of crewmen and procedural practices should be implemented to eliminate attempts to mate or demate connectors while energized and to minimize mis-connections. A second verification of proper mating should be made prior to energizing. A connector verification system should be part of the connector system.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				Marginal

35

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED

INTERFACE HAZARD ANALYSIS

PAGE ___ OF ___
DATE ___
REV ___

END ITEM Orbiter	SUBSYSTEM Mechanical	SUBSYSTEM IDENT NO. 4
OPERATION/PHASE Orbital - Uncouple/undock from payload		OP. IDENT. NO. C
HAZARD GROUP Disturbance		HAZARD GRP. CODE 12
REFERENCES FMEA 3.6 FMEA 5.6		AUTHORITY Project II, Task II-3

HAZARD DESCRIPTION/ EFFECTS A failure in the manipulator which precludes release from the payload such that separation cannot be accomplished without EVA action by the crew presents a hazard in the repair operation. This hazard is initiated under the condition where the thrusters activate during or at the time the crewmen effects release of the manipulator. The thrusters may have imparted energy into the manipulators which at release could spring back to strike the crewman.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			Critical

COPIES TO: STRUCTURAL ___ MECHANICAL ___ MATERIALS ___ GSE ___ OTHER ___

AVIONICS ___ PROPULSION ___ VEHICLE SUPPORT ___ FACILITIES ___ PAYLOAD ___ SYS SAFETY X

ACTION RECOMMENDED:

Manipulators should be provided with back-up release mechanisms. Thrusters should be locked out prior to any attempts to repair manipulators.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				Marginal

36

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED ______

OPERATIONAL
HAZARD ANALYSIS

PAGE ____ OF ____
DATE ______
REV ______

END ITEM Shuttle Orbiter	SUBSYSTEM Mechanical	SUBSYSTEM IDENT NO. 4
OPERATION/PHASE Orbital-Uncouple/undock from payload		OP. IDENT. NO. C
HAZARD GROUP Impact		HAZARD GRP. CODE 8
REFERENCES FMEA 3.6 FMEA 5.6		AUTHORITY Project II Task II-3

HAZARD DESCRIPTION/ EFFECTS In the situation where power is applied to the manipulator for the purpose of releasing and moving the arm away from the payload, if binding occurs with a sudden tension release, the payload could be impacted by the manipulator due to stored energy release.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			Critical

COPIES TO: STRUCTURAL ____ MECHANICAL ____ MATERIALS ____ GSE ____ OTHER ____

AVIONICS ____ PROPULSION ____ VEHICLE SUPPORT ____ FACILITIES ____ PAYLOAD ____ SYS SAFETY X

ACTION RECOMMENDED:

Limiting devices should be incorporated in the manipulator system to limit the energy that could be imparted to a safe level.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				Marginal

37

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED ______

INTERFACE
HAZARD ANALYSIS

PAGE ____ OF ____
DATE ______
REV ______

END ITEM Shuttle Orbiter	SUBSYSTEM Mechanical	SUBSYSTEM IDENT NO. 4
OPERATION/PHASE Orbital-Uncouple/undock from payload		OP. IDENT. NO. C
HAZARD GROUP Loss of habitable environment		HAZARD GRP. CODE 10
REFERENCES FMEA 3.6 FMEA 5.6		AUTHORITY Project II, Task II-3

HAZARD DESCRIPTION/ EFFECTS Disturbances imparted to the docking adapter ring, through use of the manipulators, propellant sloshing, rotational forces and stabilization actions could fatigue the docking adapter, causing cracks through which environmental fluids could escape. Should this rupture in a mode to cause rapid decompression, assuming the hatch door is open for crew traffic, the crew could be lost.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			Critical

COPIES TO: STRUCTURAL ____ MECHANICAL ____ MATERIALS ____ GSE ____ OTHER ____

AVIONICS ____ PROPULSION ____ VEHICLE SUPPORT ____ FACILITIES ____ PAYLOAD ____ SYS SAFETY X

ACTION RECOMMENDED:

The docking adapter should be designed, developed and proof tested to verify that it can withstand the loads to which it will be repeatedly subjected. Provide patches that can be applied inside the adapter ring.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				Marginal

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED ____

OPERATIONAL
HAZARD ANALYSIS

PAGE ____ OF ____
DATE ____
REV ____

END ITEM Shuttle Orbiter	SUBSYSTEM Propulsion	SUBSYSTEM IDENT NO. 2
OPERATION/PHASE Orbital-Separate to safe distance from buildup operation		OP. IDENT. NO. C
HAZARD GROUP Impact		HAZARD GRP. CODE 8
REFERENCES FMEA 3.7 FMEA 5.7		AUTHORITY Project II, Task II-3

HAZARD DESCRIPTION/ EFFECTS

In conducting the translation maneuver during separation from the buildup operation, failure or intermittent burning on one bank of RCS engines could pitch the orbiter when in close proximity to the LSF, which may cause impact to occur. This could create structural damage and if the impact is strong enough, could possible fracture the crew compartment causing loss of habitable environment, or crack the thermal protection insulation.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			Critical

COPIES TO: STRUCTURAL ____ MECHANICAL ____ MATERIALS ____ GSE ____ OTHER ____

AVIONICS ____ PROPULSION ____ VEHICLE SUPPORT ____ FACILITIES ____ PAYLOAD ____ SYS SAFETY X

ACTION RECOMMENDED:

To prevent or minimize intermittent operation of the RCS, secondary RCS controls should be provided to insure operation in case the primary controls fail.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				Marginal

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED ______

OPERATIONAL
HAZARD ANALYSIS

PAGE ____ OF ____
DATE ______
REV ______

END ITEM Shuttle Orbiter/LSF	SUBSYSTEM Human	SUBSYSTEM IDENT NO. 12
OPERATION/PHASE Orbital - Separate to safe distance from buildup operations		OP. IDENT. NO. C
HAZARD GROUP Impact		HAZARD GRP. CODE 8
REFERENCES FMEA 3.7	FMEA 5.7	AUTHORITY Project II, Task II-3

HAZARD DESCRIPTION/ EFFECTS

The introduction of an erroneous control maneuver command by the crew could effectively cause an impact between the vehicle and LSF. This hazard could be the result of a diurnal schedule, loss of sleep and extended work schedules, causing fatigue and other disorientation factors. Under this condition the efficiency of the crew may be low and translation into rather than away from the LSF may be the result of erroneous action taken by the crew. The impact may damage the TPI causing loss of the orbiter during re-entry.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			Critical

COPIES TO: STRUCTURAL ____ MECHANICAL ____ MATERIALS ____ GSE ____ OTHER ____

AVIONICS ____ PROPULSION ____ VEHICLE SUPPORT ____ FACILITIES ____ PAYLOAD ____ SYS SAFETY X

ACTION RECOMMENDED:

With ground assistance the vehicle commander should have the capability to evaluate crew proficiency as a result of fatigue. No crew member should be permitted in a control situation where the safety of the vehicle and crew could be adversely affected by errors of judgement or action brought on by fatigue.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				Marginal

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED ______

OPERATIONAL

HAZARD ANALYSIS

PAGE ____ OF ____

DATE ______

REV ______

END ITEM Orbiter/LSF	SUBSYSTEM Propulsion	SUBSYSTEM IDENT NO. 2
OPERATION/PHASE Orbital-Separate to safe distance from buildup operation		OP. IDENT. NO. C
HAZARD GROUP Impact, loss of habitable environment		HAZARD GRP. CODE 8, 10
REFERENCES FMEA 3.7 FMEA 5.7		AUTHORITY

HAZARD DESCRIPTION/ EFFECTS During the initial movement of translation a hazard can be created if there is a failure to stabilize the orbiter. Instability could occur through human error, intermittent operation of outboard RCS engines, or venting of propulsive vents when not desired. Any combination which causes roll or a pitching movement in the Orbiter could cause impact damage. The extreme hazard would be loss of the habitable environment due to rupture of the pressure hull with loss of the vehicle upon re-entry.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			Critical

COPIES TO: STRUCTURAL ____ MECHANICAL ____ MATERIALS ____ GSE ____ OTHER ____

AVIONICS ____ PROPULSION ____ VEHICLE SUPPORT ____ FACILITIES ____ PAYLOAD ____ SYS SAFETY X

ACTION RECOMMENDED:

The RCS must be capable of compensating for propulsive venting and the controls should be provided with secondary capability to operate should the primary mode fail. The operator should be trained to minimize human error.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				Marginal

41

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED ____

OPERATIONAL
HAZARD ANALYSIS

PAGE ____ OF ____
DATE ____
REV ____

END ITEM LSF/Space Shuttle Propellant Module/Storage — SUBSYSTEM Propulsion	SUBSYSTEM IDENT NO. 2
OPERATION/PHASE Station Orbital-Deploy propellant module	OP. IDENT. NO. C
HAZARD GROUP Impact/Explosion	HAZARD GRP. CODE 8, 1
REFERENCES (EOS to storage facility (direct) MSC-00759 SD70-540 FMEA 4.3 Contract NAS9-9953	AUTHORITY Task II-3.3

HAZARD DESCRIPTION/ EFFECTS

The change in controllability of the Space Shuttle, due to the CG shift caused by transpositioning the propellant module from the cargo bay to the docking attitude, will change the pitch characteristics of the shuttle during RCS operation. This in turn could cause off center docking mechanism impact or impact of the propellant module structure with the propellant depot causing potentially explosive conditions.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			Catastrophic

COPIES TO: STRUCTURAL ____ MECHANICAL ____ MATERIALS ____ GSE ____ OTHER ____

AVIONICS X PROPULSION X VEHICLE SUPPORT ____ FACILITIES ____ PAYLOAD ____ SYS SAFETY X

ACTION RECOMMENDED:

Provide control sensitivity in the stabilization system which will allow translation of the Space Shuttle without overcontrol during the docking maneuver.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				Marginal

42

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED

INTERFACE

HAZARD ANALYSIS

PAGE ____ OF ____

DATE ____

REV ____

END ITEM LSF/Propellant Module	SUBSYSTEM Propellant Transfer	SUBSYSTEM IDENT NO. 11
OPERATION/PHASE Orbital-Transfer/unload propellants		OP. IDENT. NO. C
HAZARD GROUP Reduced integrity of structure or equipment		HAZARD GRP. CODE 2
REFERENCES FMEA 4.5		AUTHORITY Project II, Task II-3

HAZARD DESCRIPTION/ EFFECTS A hazard exists during preparation for transfer hookup when the line interconnect fixture meteoroid shield has not been retracted prior to docking. The hazard results in damage to the indexing probes as they are forced into the shield instead of the mating interconnect half. The affect of this damage would result in loss of capability to rigidize the interface for transfer line connection. This damage of capability to rigidize the interface for transfer line connection. This damage may also cause the index probe chain drive to break rendering the system inoperative.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			Critical

COPIES TO: STRUCTURAL ____ MECHANICAL X MATERIALS ____ GSE ____ OTHER ____

AVIONICS ____ PROPULSION ____ VEHICLE SUPPORT ____ FACILITIES ____ PAYLOAD X SYS SAFETY X

ACTION RECOMMENDED:

Provide a meteoroid shield design for the line interconnect fixture which is capable of being retracted before and after docking, and incorporating the capability for automatic withhold of probe and line extension activation when the shield is not retracted.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				Negligible

43

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED

INTEGRATION

HAZARD ANALYSIS

PAGE ____ OF ____

DATE ____

REV ____

END ITEM LSF	SUBSYSTEM Propellant Transfer	SUBSYSTEM IDENT NO. II
OPERATION/PHASE Orbital-Transfer/unload propellants		OP. IDENT. NO. C
HAZARD GROUP Fire/Explosion, Heat/Temperature		HAZARD GRP. CODE 1, 6
REFERENCES FMEA 4.5		AUTHORITY Project II, Task II-3

HAZARD DESCRIPTION/ EFFECTS

Mechanical failure of the line extension bellows in the line interconnect fixture would produce a potential fire or explosion if the fixture is not open to ambient pressure. A mass spill by rupture will create a hazard in the docking area caused by ice crystal formation over the structures and in the surrounding areas. This condition could affect the interfacing systems adversely, and will cause delay of the mission.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			Critical

COPIES TO: STRUCTURAL X MECHANICAL X MATERIALS ____ GSE ____ OTHER ____

AVIONICS ____ PROPULSION ____ VEHICLE SUPPORT ____ FACILITIES ____ PAYLOAD ____ SYS SAFETY X

ACTION RECOMMENDED:

Perform proof and life testing of line extension bellows to verify performance capability. Provide automatic shutoff valves in the lines, located such that the fluid flow can be shut off to the bellows segment.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				Marginal

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED

OPERATIONAL
HAZARD ANALYSIS

PAGE ___ OF ___
DATE ___
REV ___

END ITEM LSF/Propellant Module	SUBSYSTEM Mechanical	SUBSYSTEM IDENT NO. 4
OPERATION/PHASE Orbital-Transfer/unload propellants (Propellant module to LSF)		OP. IDENT. NO. C
HAZARD GROUP Explosion		HAZARD GRP. CODE 1
REFERENCES FMEA 4.5 FMEA 5.10		AUTHORITY Task II-3

HAZARD DESCRIPTION/ EFFECTS Upon completion of the rigidizing process for the line interconnect fixture, the line connections are accomplished. Failure of the line quick disconnect to seal presents a hazard created by fluid leakage. Where the line leakage is capable of being contained due to the compartment not being vented to ambient, the contained fluids could create an explosion. The cause of not sealing properly could be contamination or a defective seal.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			Critical

COPIES TO: STRUCTURAL ___ MECHANICAL ___ MATERIALS ___ GSE ___ OTHER ___

AVIONICS ___ PROPULSION ___ VEHICLE SUPPORT ___ FACILITIES ___ PAYLOAD ___ SYS SAFETY X

ACTION RECOMMENDED:

The line interconnect fixture should not be in an enclosed space. Means should be provided to verify that the line connection is leak-tight prior to initiating propellant flow.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				Marginal

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED ______

HAZARD ANALYSIS

PAGE ____ OF ____
DATE ______
REV ______

END ITEM Propellant Module/LSF	SUBSYSTEM Propulsion	SUBSYSTEM IDENT NO. 2
OPERATION/PHASE Orbital-Transfer/unload propellants		OP. IDENT. NO. C
HAZARD GROUP Loss of attitude control, disturbances		HAZARD GRP. CODE 9 12
REFERENCES FMEA 4.5		AUTHORITY Project II, Task II-3

HAZARD DESCRIPTION/ EFFECTS The spin-up operation using the reaction control system could create hazards associated with "G" loads and disturbances due to sloshing. The hazard can be caused by application of thrust to the LSF which in turn initiates the condition for sloshing. Any intermittent firing from the RCS could amplify the sloshing which through coupling with the LSF could be destructive. The conditions for intermittent firing could be set by uncovering of the propellant inlet in the source tanks due to severe distortion of the liquid surface. Any unevenness in spin rate or side motions can cause undesirable propellant motion.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			Critical

COPIES TO: STRUCTURAL ____ MECHANICAL ____ MATERIALS ____ GSE ____ OTHER ____

AVIONICS ____ PROPULSION ____ VEHICLE SUPPORT ____ FACILITIES ____ PAYLOAD ____ SYS SAFETY X

ACTION RECOMMENDED:

Slosh dampening devices shoild be designed into the LSF tanks to dampen out sloshing so that it is not amplified. An accumulator should be provided for the RCS propellant supply to isolate them from disturban ces in the main tanks. Back-up RCS controls should be provided to insure continuous operation.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				Marginal

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED ______

INTEGRATION

HAZARD ANALYSIS

PAGE ____ OF ____

DATE ______

REV ______

END ITEM Propellant Module/LSF

SUBSYSTEM Propellant

SUBSYSTEM IDENT NO. 11

OPERATION/PHASE Orbital-Transfer/Unload Propellants

OP. IDENT. NO. C

HAZARD GROUP Reduced integrity of structure or equipment

HAZARD GRP. CODE 2

REFERENCES FMEA 4.5

AUTHORITY Project II, Task II-3

HAZARD DESCRIPTION/ EFFECTS

Lack of a zero "G" propellant gaging system in the LSF baseline places increased importance on the system flowmeters. Failure of a flowmeter creates hazards in the following manner. Loss of accurate transfer data through electromechanical failure or two phase flow caused by disturbances causes loss of data on CG location requiring extrapolation from last known condition. The lack of accurate data thus aggravates the disturbance factors and CG control. The extreme hazard could result in loss of mission through structural failure due to vehicle and propellant dynamic interaction.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			Critical

COPIES TO: STRUCTURAL ____ MECHANICAL ____ MATERIALS ____ GSE ____ OTHER ____

AVIONICS ____ PROPULSION ____ VEHICLE SUPPORT ____ FACILITIES ____ PAYLOAD ____ SYS SAFETY X

ACTION RECOMMENDED:

Provide back-up flowmeters and sensing devices.
A development program should be initiated to develop a zero "G" propellant gaging system.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				Critical

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED ______

OPERATIONAL HAZARD ANALYSIS

PAGE ____ OF ____
DATE ______
REV ______

END ITEM Equipment Module	**SUBSYSTEM** Pressurization	**SUBSYSTEM IDENT NO.** 13
OPERATION/PHASE Orbital-Transfer/Unload Propellants		**OP. IDENT. NO.** C
HAZARD GROUP Heat/Temperature		**HAZARD GRP. CODE** 6
REFERENCES FMEA 4.5 Transfer/unload propellants		**AUTHORITY** Project II, Task II-3

HAZARD DESCRIPTION/ EFFECTS Failure of the LO_2 regulator to the gas generator, in the open mode will allow an oxygen rich condition to occur within the gas generator which if undetected or not shutdown will cause excessive temperatures within the GG to the heat exchanger. This condition could reasonably be expected to cause burnthrough of the GG and heat exchanger located in the equipment module. The extent of the hazard is dependent on shutdown action or operation of the safety devices.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			Critical

COPIES TO: STRUCTURAL ____ MECHANICAL ____ MATERIALS ____ GSE ____ OTHER ____

AVIONICS ____ PROPULSION ____ VEHICLE SUPPORT ____ FACILITIES ____ PAYLOAD ____ SYS SAFETY X

ACTION RECOMMENDED:

Safety devices should be incorporated to sense the gas generator exhaust gas temperature and pressure and automatically terminate propellant flow to gas generator when these measurements exceed pre-set, safe limits until repairs can be made.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				Marginal

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED

INTERFACE

HAZARD ANALYSIS

PAGE ____ OF ____

DATE ____

REV ____

END ITEM LSF/Equipment Module	SUBSYSTEM Mechanical	SUBSYSTEM IDENT NO. 1
OPERATION/PHASE Orbital-Transfer/unload propellants		OP. IDENT. NO. C
HAZARD GROUP Reduced integrity of structure or equipment		HAZARD GRP. CODE 2
REFERENCES FMEA 4.5		AUTHORITY Project II Task II-3

HAZARD DESCRIPTION/ EFFECTS

The gas generator fuel supply pump provides fuel to the combustor under an NPSH from an initial NPSH of zero. In the bootstrap operation cavitation due to erratic fuel flow to the pump could restrict the output head below the point where the heat exchanger could operate in a stable condition. The oscillations within the heat exchanger could create internal damage or reduce the heat exchanger integrity.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			Critical

COPIES TO: STRUCTURAL ____ MECHANICAL ____ MATERIALS ____ GSE ____ OTHER ____

AVIONICS ____ PROPULSION ____ VEHICLE SUPPORT ____ FACILITIES ____ PAYLOAD ____ SYS SAFETY X

ACTION RECOMMENDED:

Provide an accumulator to insure liquid propellants are available to GG.
Design, develop and proof-test the heat exchanger to operate under all possible pressure fluctuations to which it might be exposed.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				Marginal

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED ______

INTEGRATION

HAZARD ANALYSIS

PAGE ____ OF ____
DATE ______
REV ______

END ITEM Equipment Module	**SUBSYSTEM** Pressurization	**SUBSYSTEM IDENT NO.** 13
OPERATION/PHASE Orbital-Transfer/Unload Propellants (LSF)		**OP. IDENT. NO.** C
HAZARD GROUP Fire/Explosion, Contamination		**HAZARD GRP. CODE** 1, 3
REFERENCES FMEA 4.5		**AUTHORITY** Project II, Task II-3

HAZARD DESCRIPTION/ EFFECTS Hot gas from the gas generator to the heat exchanger could exceed the design limit temperature, should a control failure occur. A hazard is thus created by possible burn through of the heat exchanger, resulting in fire in the Equipment Module. Should the heat exchanger burn through occur in the exchanger walls, the equipment module would be filled with products of combustion. The magnitude of the destructive effects of this type hazard are dependent on reaction time of the crew and/or safety devices.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			Critical

COPIES TO: STRUCTURAL ____ MECHANICAL ____ MATERIALS ____ GSE ____ OTHER ____

AVIONICS ____ PROPULSION ____ VEHICLE SUPPORT ____ FACILITIES ____ PAYLOAD ____ SYS SAFETY X

ACTION RECOMMENDED: Safety devices should be incorporated to sense the gas generator exhaust gas temperature and pressure and automatically terminate propellant flow to gas generator. When these measurements exceed pre-set safe limits.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				Marginal

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED ______

INTEGRATION

HAZARD ANALYSIS

PAGE ____ OF ____

DATE ______

REV ______

END ITEM Propellant Module/LSF	SUBSYSTEM Propellant	SUBSYSTEM IDENT NO. 11
OPERATION/PHASE Orbital-Transfer/Unload Propellants		OP. IDENT. NO. C
HAZARD GROUP Disturbances		HAZARD GRP. CODE 12
REFERENCES FMEA 4.5		AUTHORITY Project II Task II-3

HAZARD DESCRIPTION/ EFFECTS Hazards are created by vehicle and propellant dynamic interactions which can cause (1) uncovering of the outlet in the source tanks, (2) venting of liquid from the receiver tank, (3) structural failure and (4) gas entrapment within the receiver tank capillary compartments. The vehicle and propellant dynamics interaction are caused by (2) CG changes due to fluid transfer from tank to tank and (b) propellant CG excursion (sloshing) within each tank. The affects of this hazard lead to instability (disturbances), possible pump cavitation, slug flow between tanks and structural failure with loss of mission or crew.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			Catastrophic

COPIES TO: STRUCTURAL ____ MECHANICAL ____ MATERIALS ____ GSE ____ OTHER ____

AVIONICS ____ PROPULSION ____ VEHICLE SUPPORT ____ FACILITIES ____ PAYLOAD ____ SYS SAFETY X

ACTION RECOMMENDED:

Slosh dampening devices should be designed into the LSF and user vehicle.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				Marginal

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED ______

OPERATIONAL HAZARD ANALYSIS

PAGE ____ OF ____

DATE ______

REV ______

END ITEM Propellant Module/LSF	SUBSYSTEM Propellant	SUBSYSTEM IDENT NO. 11
OPERATION/PHASE Orbital-Transfer/Unload Propellants		OP. IDENT. NO. C
HAZARD GROUP Disturbances		HAZARD GRP. CODE 12
REFERENCES FMEA 4.5		AUTHORITY Project II, Task II-3

HAZARD DESCRIPTION/ EFFECTS A potential hazard is created during propellant transfer operations in near Zero "G" associated with receiver tank inlet fluid momentum. There is a possibility of severe distortion of the liquid surface due to the flow energy, which can cause disturbances in the vehicle capable of becoming destructive. As propellant inlet momentum increases, resulting surface disturbance will also increase. The effect of this hazard can lead to severe instability, structural failure and loss of mission, through CG excursion.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			Catastrophic

COPIES TO: STRUCTURAL ____ MECHANICAL ____ MATERIALS ____ GSE ____ OTHER ____

AVIONICS ____ PROPULSION ____ VEHICLE SUPPORT ____ FACILITIES ____ PAYLOAD ____ SYS SAFETY X

ACTION RECOMMENDED:

Slosh dampening devices should be designed into the LSF and propellant module. Procedural controls should be implemented to slow down or stop propellant transfer under geysering conditions.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				Critical

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED

INTERFACE

HAZARD ANALYSIS

PAGE ____ OF ____

DATE ____

REV ____

END ITEM Propellant Module/LSF	SUBSYSTEM Mechanical	SUBSYSTEM IDENT NO. 4
OPERATION/PHASE Orbital-Retrieve Empty Down-Propellant Module		OP. IDENT. NO. C
HAZARD GROUP Reduced integrity of structure or equipment		HAZARD GRP. CODE 2
REFERENCES FMEA 4.6		AUTHORITY Project II, Task II-3

HAZARD DESCRIPTION/ EFFECTS The indexing probes at the corners of the line interconnect fixture are used to rigidize the interface for line hookup. A hazard to the LSF could be created with failure of the indexing probes to release, or through improper procedures, allowing the interface to be derigidized but not detached. Movement of the propellant module under this condition could bend the interface probe connections, and depending on the applied force, could crush or damage the interconnect lines.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			Critical

COPIES TO: STRUCTURAL ____ MECHANICAL ____ MATERIALS ____ GSE ____ OTHER ____

AVIONICS ____ PROPULSION ____ VEHICLE SUPPORT ____ FACILITIES ____ PAYLOAD ____ SYS SAFETY X

ACTION RECOMMENDED: A secondary release mechanism should be incorporated into line interconnect fixture.

A means should be incorporated in docking mechanism to enable control pilot to determine that indexing probes had released and to insure release prior to attempting translation.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				Marginal

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED ______

OPERATIONAL
HAZARD ANALYSIS

PAGE ____ OF ____
DATE ______
REV ______

END ITEM LSF/Propellant Module	SUBSYSTEM Mechanical	SUBSYSTEM IDENT NO. 4
OPERATION/PHASE Orbital-Retrieve empty down propellant module		OP. IDENT. NO. C
HAZARD GROUP Implosion, Disturbances		HAZARD GRP. CODE 1, 12
REFERENCES FMEA 4.6		AUTHORITY Task II-3

HAZARD DESCRIPTION/EFFECTS Failure of the QD for the pressurization line in the propellant module, during module separation from the LSF, when being retrieved by the Shuttle manipulators would cause tank venting through the QD at a distance from the shuttle of over 60 feet (manipulator arm length). This reaction could load the manipulator arms against the shuttle stabilization system causing pitching action and creating a disturbance in the propellant tanks of the shuttle. With the loss of module tank pressurization, and no makeup, the tank would implode upon re-entry in the orbiter cargo bay.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			Catastrophic

COPIES TO: STRUCTURAL ____ MECHANICAL ____ MATERIALS ____ GSE ____ OTHER ____

AVIONICS ____ PROPULSION ____ VEHICLE SUPPORT ____ FACILITIES ____ PAYLOAD ____ SYS SAFETY X

ACTION RECOMMENDED:

The module release mechanism should separate the disconnect prior to final release from LSF. At this time it could be determined by visual contact that disconnect was leaking. A remotely operated valve should be incorporated in the pressurization line to provide back-up capability to shut-off gas.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				Marginal

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED ____

INTEGRATION
HAZARD ANALYSIS

PAGE ____ OF ____
DATE ____
REV ____

END ITEM Shuttle Orbiter	SUBSYSTEM Avionics	SUBSYSTEM IDENT NO. 1
OPERATION/PHASE Orbital-Rendezvous with Tug/Equipment, Propellant or Support Modules		OP. IDENT. NO. C
HAZARD GROUP Reduced integrity of structure or equipment		HAZARD GRP. CODE 2
REFERENCES FMEA 5.2		AUTHORITY Project II, Task II-3

HAZARD DESCRIPTION/ EFFECTS Failure of the on-board computer could create a hazardous condition manifest in many ways, depending on the timeline and proximity to the target. The inability to perform in close proximity could cause impact damage, loss of stabilization through improper inputs to the RCS, and possible loss of capability to communicate with the target. Since the computer is involved with all aspects of the rendezvous operation any failure which cannot be corrected could cause potential catastrophy. The extreme failure would be loss of attitude control with rescue required if the crew is to survive.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			Catastrophic

COPIES TO: STRUCTURAL ____ MECHANICAL ____ MATERIALS ____ GSE ____ OTHER ____

AVIONICS ____ PROPULSION ____ VEHICLE SUPPORT ____ FACILITIES ____ PAYLOAD ____ SYS SAFETY X

ACTION RECOMMENDED:

Redundancy should be incorporated into the computer to insure operability during critical operations. The operating status and mode should be displayed to the crew to give advance warning of the requirement for manual control.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				Marginal

55

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED

INTERFACE
HAZARD ANALYSIS

PAGE ___ OF ___
DATE ___
REV ___

END ITEM Shuttle Orbiter	SUBSYSTEM Vehicle Support-Manipulators	SUBSYSTEM IDENT NO. 3
OPERATION/PHASE Orbital-Dock		OP. IDENT. NO. C
HAZARD GROUP Disturbances		HAZARD GRP. CODE 12
REFERENCES FMEA 5.3 FMEA 5.9		AUTHORITY

HAZARD DESCRIPTION/ EFFECTS

The docking adapter latches are controlled by torque applied by the manipulator to the pinion gear. In the case where the latches have been retracted and the chain drive fails such that the pinion is wedged (will not rotate) the latches may not operate. Effort by the manipulator wrist to effect latching could transmit disturbances into the shuttle orbiter causing sloshing.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			Critical

COPIES TO: STRUCTURAL ___ MECHANICAL ___ MATERIALS ___ GSE ___ OTHER ___

AVIONICS ___ PROPULSION ___ VEHICLE SUPPORT ___ FACILITIES ___ PAYLOAD ___ SYS SAFETY X

ACTION RECOMMENDED:

Back-up separation devices should be incorporated into the docking adapter to be used in case the primary mode fails.

Limiting devices should be incorporated into manipulator system to limit the energy that could be imparted to a safe level.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				Marginal

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED

OPERATIONAL HAZARD ANALYSIS

PAGE ___ OF ___
DATE ___
REV ___

END ITEM That which is receiving maintenance	SUBSYSTEM Propellant	SUBSYSTEM IDENT NO. II
OPERATION/PHASE Orbital - Unload maintenance crew and conduct minor maintenance		OP. IDENT. NO. C
HAZARD GROUP Contamination		HAZARD GRP. CODE 3
REFERENCES FMEA 5.4		AUTHORITY Project II, Task II-3

HAZARD DESCRIPTION/EFFECTS During maintenance operations in orbit a variety of postulated conditions could create hazards during the operations. One such hazard is a procedural error of the crew wherein the maintenance, procedurally, is not accomplished. This is the step which purges the system after maintenance. The error is "not accomplishing purging" or "improperly purging the system" and could lead to system contamination, possible loss of system capability and if involved with the ECLSS could lead to loss of a habitable environment for the crew.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			Critical

COPIES TO: STRUCTURAL ___ MECHANICAL ___ MATERIALS ___ GSE ___ OTHER ___

AVIONICS ___ PROPULSION ___ VEHICLE SUPPORT ___ FACILITIES ___ PAYLOAD ___ SYS SAFETY X

ACTION RECOMMENDED:

Ground monitors that are not subject to distractions should monitor the progress of maintenance operations to alert crew to critical omissions or procedural errors.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				Marginal

57

CONTRACT NAS8-27692 | OPERATIONAL HAZARD ANALYSIS | PAGE ____ OF ____
LOCATION/SITE INVOLVED ____ | DATE ____
REV ____

END ITEM That which is receiving maintenance	SUBSYSTEM Propellant	SUBSYSTEM IDENT NO. 11
OPERATION/PHASE Orbital - Unload maintenance crew and conduct minor maintenance operations		OP. IDENT. NO. C
HAZARD GROUP Contamination		HAZARD GRP. CODE 3
REFERENCES FMEA 5.4		AUTHORITY Project II, Task II-3

HAZARD DESCRIPTION/ EFFECTS In orbital maintenance, replacement of valving in the propellant system can establish the conditions for introduction of a hazard. The possibility exists that a valve could be installed with the flange blanking plate or dust cover left in the system. This could occur from lack of crew training or familiarity with the correct installation. Once installed the material could be swallowed by the system, contaminating the system. If this should occur within the ECLSS the system could be rendered inoperative for crew use.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			Critical

COPIES TO: STRUCTURAL ____ MECHANICAL ____ MATERIALS ____ GSE ____ OTHER ____

AVIONICS ____ PROPULSION ____ VEHICLE SUPPORT ____ FACILITIES ____ PAYLOAD ____ SYS SAFETY X

ACTION RECOMMENDED:
Prior to maintenance operations it should be verified that the personnel involved are trained and knowledgeable. During maintenance operations the crew should be guided by procedural controls. Blanking plates should be designed with external tabs to signal their presence by inspection. Ground monitors should check progress of maintenance operations to alert crew to procedural omissions.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				Marginal

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED ______

INTEGRATION
HAZARD ANALYSIS

PAGE ____ OF ____
DATE ______
REV ______

END ITEM That which is receiving maintenance operation — **SUBSYSTEM** Avionics	**SUBSYSTEM IDENT NO.** 1
OPERATION/PHASE Orbital - Unload maintenance crew and conduct minor maintenance operations	**OP. IDENT. NO.** C
HAZARD GROUP Loss of communication	**HAZARD GRP. CODE** 11
REFERENCES FMEA 5.4	**AUTHORITY**

HAZARD DESCRIPTION/ EFFECTS Failure of intra or inter-vehicle communications during the maintenance operations subjects the crew to a communication blackout which carries the hazard of potential inability to coordinate operations between the vehicle, ground base and orbiter. This can lead to inadvertent or erroneous actions which may be responsible for system activation, while the crew is in the area of an "open" or "down" system. Without proper system statusing the crew is then subjected to potential shock or habitable environment contamination.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			Catastrophic

COPIES TO: STRUCTURAL ___ MECHANICAL ___ MATERIALS ___ GSE ___ OTHER ___

AVIONICS ___ PROPULSION ___ VEHICLE SUPPORT ___ FACILITIES ___ PAYLOAD ___ SYS SAFETY X

ACTION RECOMMENDED: Redundancy should be incorporated in communications systems to insure continuous contact between crews. Alternate systems should be used while primary system is being repaired. When contact between operating crews is lost no action should be performed that could affect other crew members until communications are restored.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				Marginal

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED ______

OPERATIONAL HAZARD ANALYSIS

PAGE ____ OF ____

DATE ______

REV ______

END ITEM That which is receiving maintenance operation

SUBSYSTEM Avionics, Mechanical

SUBSYSTEM IDENT NO. 1, 4

OPERATION/PHASE Orbital - Unload maintenance crew and conduct minor maintenance

OP. IDENT. NO. C

HAZARD GROUP Reduced integrity of structure or equipment, contamination

HAZARD GRP. CODE 2, 3

REFERENCES FMEA 5.4

AUTHORITY Project II, Task II-3

HAZARD DESCRIPTION/ EFFECTS

Incorrect procedures or human error in making line connections during maintenance could cause hazards related to fire, pressure, fragmentation and contamination. An example is interchanging nitrogen tetroxide (N_2O_4) lines with Hydrazine (N_2H_4) lines.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			Critical

COPIES TO: STRUCTURAL ____ MECHANICAL ____ MATERIALS ____ GSE ____ OTHER ____

AVIONICS ____ PROPULSION ____ VEHICLE SUPPORT ____ FACILITIES ____ PAYLOAD ____ SYS SAFETY X

ACTION RECOMMENDED:

Adjacent or incompatible line connections should be sized or configured to minimize possibility of cross-connection. Maintenance personnel should be trained and procedural controls should be implemented to minimize human errors. Lines, connections, should be properly identified on both sides of inter-connect point.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				Marginal

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED ______

OPERATIONAL

HAZARD ANALYSIS

PAGE ____ OF ____

DATE ______

REV ______

END ITEM That which is receiving maintenance	SUBSYSTEM Avionics, Propellant, Propulsion	SUBSYSTEM IDENT NO. 1, 11, 2
OPERATION/PHASE Orbital - *Unload maintenance crew and conduct minor* maintenance operations		OP. IDENT. NO. C
HAZARD GROUP Reduced integrity of structure or equipment, loss of habitable environment		HAZARD GRP. CODE 2, 10
REFERENCES FMEA 5.4		AUTHORITY Project II, Task II-3

HAZARD DESCRIPTION/EFFECTS Operations during checkout which require a coordinated effort between ground based facilities and the orbiting unit, such as LSF, can introduce hazards during maintenance operations. The maintenance crew will call for a system to be energized by the ground, or the orbiter. If an erroneous signal is given which is not procedurally in sync with the operation, valves may be erroneously opened or systems activated which could damage the system, cause subsystem failures and possibly injure the maintenance crew, i.e., pressurization valves, automatic switches, transfer valves, etc.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			Critical

COPIES TO: STRUCTURAL ____ MECHANICAL ____ MATERIALS ____ GSE ____ OTHER ____

AVIONICS ____ PROPULSION ____ VEHICLE SUPPORT ____ FACILITIES ____ PAYLOAD ____ SYS SAFETY X

ACTION RECOMMENDED:

To reduce the risk of transmission or communication errors, local control should be utilized to extent possible. Should ground control be necessary procedural controls should be implemented to insure coordinated effort.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				Marginal

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED ____

OPERATIONAL

HAZARD ANALYSIS

PAGE ____ OF ____

DATE ____

REV ____

END ITEM That which is receiving maintenance	**SUBSYSTEM** Avionics	**SUBSYSTEM IDENT NO.** I
OPERATION/PHASE Orbital - Unload maintenance crew and conduct minor maintenance operations		**OP. IDENT. NO.** C
HAZARD GROUP Reduced integrity of structure or equipment		**HAZARD GRP. CODE** 2
REFERENCES FMEA 5.4		**AUTHORITY** Project II, Task II-3

HAZARD DESCRIPTION/ EFFECTS Failure to conduct electrical system repair to the proper procedures can introduce hazards in the operations. The hazard is associated with the requirement to remove electrical power from the system before repair/maintenance is started. It can be reasonably expected that under non-compliance with this requirement, the electrical system will be shorted, grounded and personnel will be subjected to burns and shock producing currents.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			Critical

COPIES TO: STRUCTURAL ____ MECHANICAL ____ MATERIALS ____ GSE ____ OTHER ____

AVIONICS ____ PROPULSION ____ VEHICLE SUPPORT ____ FACILITIES ____ PAYLOAD ____ SYS SAFETY X

ACTION RECOMMENDED:

Procedural controls should be implemented to insure that all power is removed from systems that are undergoing maintenance or repair and from adjacent systems that might be contacted by tools or parts during such activity.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				Marginal

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED ____

OPERATIONAL
HAZARD ANALYSIS

PAGE ____ OF ____
DATE ____
REV ____

END ITEM That which is receiving maintenance

SUBSYSTEM Pressurization

SUBSYSTEM IDENT NO. 13

OPERATION/PHASE Orbital - Unload maintenance crew and conduct minor meintenance operations

OP. IDENT. NO. C

HAZARD GROUP Loss of habitable environment

HAZARD GRP. CODE 10

REFERENCES FMEA 5.4

AUTHORITY Task II-3

HAZARD DESCRIPTION/ EFFECTS

Failure to relieve pressure or isolate the section of line which is to receive maintenance could create hazards as follows: (1) Fittings could fly off during unloosening causing impact damage, (2) Lines could whip in the system, (3) Loss of fluid from the line could fill the work volume with gas which renders the area uninhabitable. This may propogate into the orbiter LSS if the hatches are not configured to prevent the intrusion.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			Marginal

COPIES TO: STRUCTURAL ____ MECHANICAL ____ MATERIALS ____ GSE ____ OTHER ____

AVIONICS ____ PROPULSION ____ VEHICLE SUPPORT ____ FACILITIES ____ PAYLOAD ____ SYS SAFETY X

ACTION RECOMMENDED:

A means should be provided to vent sections of line that are subject to maintenance and to verify that such sections are free of pressure prior to disassembly. Maintenance personnel should be trained and guided by procedural controls.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				Negligible

63

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED

OPERATIONAL
HAZARD ANALYSIS

PAGE ___ OF ___
DATE ___
REV ___

END ITEM Orbiter — SUBSYSTEM Mechanical	SUBSYSTEM IDENT NO. 4
OPERATION/PHASE Orbital - Unload maintenance crew and conduct minor maintenance operations	OP. IDENT. NO. C
HAZARD GROUP Reduced integrity of structure or equipment	HAZARD GRP. CODE 2
REFERENCES FMEA 5.4	AUTHORITY

HAZARD DESCRIPTION/ EFFECTS

As fluid dewars are transferred through the internal transfer way, loss of control of the load could cause impact of the cargo with the hatch causing damage to the sealing surface. This hazard would reduce the integrity of the airlock for emergency or re-entry operations.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			Marginal

COPIES TO: STRUCTURAL ___ MECHANICAL ___ MATERIALS ___ GSE ___ OTHER ___

AVIONICS ___ PROPULSION ___ VEHICLE SUPPORT ___ FACILITIES ___ PAYLOAD ___ SYS SAFETY X

ACTION RECOMMENDED:

Guides or tracks should be provided for large, bulky or massive cargo to prevent handling errors. The crew should be trained in cargo handling to minimize human error.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				Negligible

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED

OPERATIONAL HAZARD ANALYSIS

PAGE ____ OF ____
DATE ____
REV ____

END ITEM Shuttle Orbiter	SUBSYSTEM Mechanical	SUBSYSTEM IDENT NO. 4
OPERATION/PHASE Orbital - Unload maintenance crew and conduct minor maintenance		OP. IDENT. NO. C
HAZARD GROUP Loss of habitable environment		HAZARD GRP. CODE 10
REFERENCES FMEA 5.4		AUTHORITY Task II-3

HAZARD DESCRIPTION/ EFFECTS

Premature activation of the airlock hatch pressure release valve could cause release of the life support environment in the airlock. When the crew is not suited under this condition the loss of pressure may not be detected and lead to subsequent loss of the crew.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			Catastrophic

COPIES TO: STRUCTURAL ____ MECHANICAL ____ MATERIALS ____ GSE ____ OTHER ____

AVIONICS ____ PROPULSION ____ VEHICLE SUPPORT ____ FACILITIES ____ PAYLOAD ____ SYS SAFETY X

ACTION RECOMMENDED:

Personnel training and procedural controls should be implemented to minimize human error. Provide low LSS pressure alarm.
A redundant ESS system (suit) should be provided for maintenance personnel.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				Marginal

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED ______

OPERATIONAL
HAZARD ANALYSIS

PAGE ____ OF ____
DATE ______
REV ______

END ITEM Shuttle Orbiter/LSF/Down Module	**SUBSYSTEM** Vehicle Support-Manipulators	**SUBSYSTEM IDENT NO.** 3
OPERATION/PHASE Orbital - Transfer down modules to orbiter		**OP. IDENT. NO.** C
HAZARD GROUP Impact, Disturbances		**HAZARD GRP. CODE** 8, 12
REFERENCES FMEA 5.10, 6.1		**AUTHORITY** Task II-3

HAZARD DESCRIPTION/ EFFECTS A mechanical or material failure of the manipulator due to fracture of the arm, at overstressing underload, thereby failing to control directional stability creates a hazard. Conditions which are established by this hazard are related to impact of the payload or the arm, with the orbiter or LSF. The impact is caused by uncontrolled release of energy in the form of the module movement. This impact could most reasonably be expected to occur in the area of the cargo bay but could occur within the radius of the arm. Uncontrolled movement of the module on the manipulator could create disturbances also, which affect the stability of the module.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			Critical

COPIES TO: STRUCTURAL ____ MECHANICAL ____ MATERIALS ____ GSE ____ OTHER ____

AVIONICS ____ PROPULSION ____ VEHICLE SUPPORT ____ FACILITIES ____ PAYLOAD ____ SYS SAFETY X

ACTION RECOMMENDED:

Limiting devices should be incorporated into manipulator system to limit to a safe level the energy that could be imparted by the manipulators.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				Marginal

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED ____

OPERATIONAL
HAZARD ANALYSIS

PAGE ____ OF ____
DATE ____
REV ____

END ITEM Cargo or Equipment Module	SUBSYSTEM Vehicle Support - ECLSS	SUBSYSTEM IDENT NO. 3
OPERATION/PHASE Orbital - Load maintenance crew and minor cargo		OP. IDENT. NO. C
HAZARD GROUP Loss of habitable environment		HAZARD GRP. CODE 10
REFERENCES FMEA 5.11		AUTHORITY Project II, Task II-3

HAZARD DESCRIPTION/ EFFECTS Upon completion of the maintenance effort the crew will transfer from the equipment module into the orbiter. Failure to effect sealing of the airlock doors between the module and LSF tunnel passageway, either because of procedural or mechanical seal failure, could cause an extra load on the ECLSS for makeup environment pressurization. The hazard involves the crew making excursions into the airlock without knowledge of the loss or impending loss of habitable environment. The portable life support system use could negate this hazard if the crew in the module could be transferred to the orbiter within the allowable time provided by the PLSS.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			Critical

COPIES TO: STRUCTURAL ____ MECHANICAL ____ MATERIALS ____ GSE ____ OTHER ____

AVIONICS ____ PROPULSION ____ VEHICLE SUPPORT ____ FACILITIES ____ PAYLOAD ____ SYS SAFETY X

ACTION RECOMMENDED:

Instrumentation should be provided on LSF side of airlock to verify that environmental conditions are safe in airlock prior to opening door. A redundant LSS volume (suit) should be provided during personnel transfer.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				Marginal

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED ______

OPERATIONAL
HAZARD ANALYSIS

PAGE ____ OF ____
DATE ______
REV ______

END ITEM Orbiter/ Propellant Module	SUBSYSTEM Propellant	SUBSYSTEM IDENT NO. 11
OPERATION/PHASE Orbital - Secure Module		OP. IDENT. NO. C
HAZARD GROUP Heat or Temperature		HAZARD GRP. CODE 6
REFERENCES FMEA 6.2		AUTHORITY Task II-3

HAZARD DESCRIPTION/ EFFECTS During the securing operation, tanks with residual propellants must be connected to the vent system within the cargo bay. Should automatic vent connecting fail, the crew may be subjected to vented cryogenic fluid, where venting occurs during an EVA attempt to make an emergency manual connection. Another hazard is postulated wherein the loss of vent connecting capability would allow propellant venting within the cargo bay, causing explosive/flammable ice crystals to be residual in the bay. These residual ice crystals would explode on re-entry if the stay time was not long enough to allow for them to sublime.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			Catastrophic

COPIES TO: STRUCTURAL ____ MECHANICAL ____ MATERIALS ____ GSE ____ OTHER ____

AVIONICS ____ PROPULSION ____ VEHICLE SUPPORT ____ FACILITIES ____ PAYLOAD ____ SYS SAFETY X

ACTION RECOMMENDED:
A means should be provided to verify that automatic vent connection is leak free. If automatic vent connection fails the module should be left in orbit until repairs can be made.
No attempts should be made at manual connection by a suited crew member in the confined space between module and cargo bay walls.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				Critical

68

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED ______

OPERATIONAL
HAZARD ANALYSIS

PAGE ____ OF ____
DATE ______
REV ______

END ITEM Orbiter	SUBSYSTEM Mechanical	SUBSYSTEM IDENT NO. 4
OPERATION/PHASE Orbital - Secure Module		OP. IDENT. NO. C
HAZARD GROUP Loss of communication		HAZARD GRP. CODE 11
REFERENCES FMEA 6.2		AUTHORITY Task II-3

HAZARD DESCRIPTION/ EFFECTS

Loss of communication between the crew in the equipment module and the Orbiter prior to transfer of the crew presents hazards associated with inability of each station to track the status of procedures for effecting personnel transfer. This lack of status on configuration, habitable environment, etc., leads to indirect hazards of apprehension, panic, etc. Without alternate means of communication EVA may be required.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			Critical

COPIES TO: STRUCTURAL ____ MECHANICAL ____ MATERIALS ____ GSE ____ OTHER ____

AVIONICS ____ PROPULSION ____ VEHICLE SUPPORT ____ FACILITIES ____ PAYLOAD ____ SYS SAFETY X

ACTION RECOMMENDED:

Provide back-up communications circuits that automatically switch in if the primary system fails. Communications system status should be displayed for monitoring by ground and orbiter crews.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				Marginal

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED ____

OPERATIONAL HAZARD ANALYSIS

PAGE ____ OF ____
DATE ____
REV ____

END ITEM Orbiter	SUBSYSTEM Mechanical	SUBSYSTEM IDENT NO. 4
OPERATION/PHASE Orbital-Secure Module		OP. IDENT. NO. C
HAZARD GROUP Loss of habitable environment		HAZARD GRP. CODE 10
REFERENCES FMEA 6.2		AUTHORITY Task II-3

HAZARD DESCRIPTION/ EFFECTS

After implacement of the equipment module in the cargo bay, a tunnel section port is extended to engage the payload mating ring for the purpose of personnel access to the module. Failure of the section to extend for mating, inability to mate because of misalignment, or lack of sealing at the ring could negate the access operation.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			Marginal

COPIES TO: STRUCTURAL ____ MECHANICAL ____ MATERIALS ____ GSE ____ OTHER ____

AVIONICS ____ PROPULSION ____ VEHICLE SUPPORT ____ FACILITIES ____ PAYLOAD ____ SYS SAFETY X

ACTION RECOMMENDED:

During personnel transfer suits should be worn to provide a redundant LSS to protect the crew should the primary LSS fail.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				Negligible

70

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED ______

OPERATIONAL
HAZARD ANALYSIS

DATE ______
REV ______

END ITEM Orbiter Propellant Module	SUBSYSTEM Structural	SUBSYSTEM IDENT NO. 5
OPERATION/PHASE Orbital/Deorbit/Land - Secure Module		OP. IDENT. NO. C,D, E
HAZARD GROUP Fire/Explosion/Implosion		HAZARD GRP. CODE 1
REFERENCES FMEA 6.2	Task II-3	AUTHORITY

HAZARD DESCRIPTION/ EFFECTS

During the securing process failure to maintain status of the module tank pressure above earth ambient establishes the condition for a fire or explosion hazard by implosion of the tank. The fire/explosion would be initiated by heat of re-entry, static spark, or friction after tank rupture and dispersion of the propellant vapors within the cargo bay.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			Catastrophic

COPIES TO: STRUCTURAL ____ MECHANICAL ____ MATERIALS ____ GSE ____ OTHER ____

AVIONICS ____ PROPULSION ____ VEHICLE SUPPORT ____ FACILITIES ____ PAYLOAD ____ SYS SAFETY X

ACTION RECOMMENDED:

A propellant module whose internal pressure cannot be verified to be within structural limits of ambient pressure could not be returned to ground in the shuttle. Instrumentation and procedures for pressurizing and monitoring module internal pressure will have to be provided.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				MARGINAL

71

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED ______

OPERATIONAL
HAZARD ANALYSIS

PAGE 1 OF 1
DATE ______
REV ______

END ITEM Shuttle Orbiter	SUBSYSTEM Mechanical	SUBSYSTEM IDENT NO. 4
OPERATION/PHASE Orbital - Secure Module		OP. IDENT. NO. C
HAZARD GROUP Reduced Integrity of Structure or Equipment		HAZARD GRP. CODE 2
REFERENCES FMEA 6.2		AUTHORITY PROJECT II, TASK II-3

HAZARD DESCRIPTION/ EFFECTS Failure to securely latch the forward or aft attach fittings to the module presents a delayed Hazard. The hazard can be initiated at any time a change in acceleration or direction is made. This initiation can cause movement in axial, vertical or horizontal directions restrained only by the impact of the module with the cargo bay structure. The maximum hazard is postulated to be a condition where the module has residual hydrogen in the tank, the module has shifted to the forward section of the cargo bay, and then shifts to the rear of the cargo bay with the actuation of the OMS firing for re-entry. This could lead to tank rupture, cargo bay structural damage and subsequent fire or explosion upon re-entry.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			CRITICAL

COPIES TO: STRUCTURAL ____ MECHANICAL ____ MATERIALS ____ GSE ____ OTHER ____

AVIONICS ____ PROPULSION ____ VEHICLE SUPPORT ____ FACILITIES ____ PAYLOAD ____ SYS SAFETY XX

ACTION RECOMMENDED:

Positive locking devices should be designed for shuttle cargo tie down with electrical verification of locking. Cargo should not be returned that cannot be verified to be locked in place.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				MARGINAL

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED ______

OPERATIONAL HAZARD ANALYSIS

PAGE 1 OF 1
DATE ______
REV ______

END ITEM Orbiter Propellant Module	SUBSYSTEM Propellant	SUBSYSTEM IDENT NO. 11
OPERATION/PHASE Orbital - Secure Module		OP. IDENT. NO. C
HAZARD GROUP Fire/Explosion/Implosion		HAZARD GRP. CODE 1
REFERENCES FMEA 6.2		AUTHORITY TASK II-3

HAZARD DESCRIPTION/ EFFECTS

Failure to connect the module vent lines on the propellant module to the Orbiter vent system, through improper procedures or mechanical failure, could cause venting in the cargo bay causing potential fire/explosion conditions with loss of mission and crew during the re-entry phase. This condition could occur due to propellant residuals in the module tanks.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			CATASTROPHIC

COPIES TO: STRUCTURAL ____ MECHANICAL ____ MATERIALS ____ GSE ____ OTHER ____

AVIONICS ____ PROPULSION ____ VEHICLE SUPPORT ____ FACILITIES ____ PAYLOAD ____ SYS SAFETY X

ACTION RECOMMENDED:

A means should be provided to verify that the module vent is connected to the orbiter vent and that the connection is leak free. If this condition cannot be verified the propellant module should not be returned in the shuttle.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				CRITICAL

73

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED

Integration
HAZARD ANALYSIS

DATE

REV

END ITEM Shuttle Orbiter/ Propellant Module	SUBSYSTEM Contamination	SUBSYSTEM IDENT NO. 3
OPERATION/PHASE Orbital/Deorbit/Land - Secure Module		OP. IDENT. NO. C/D/E
HAZARD GROUP Fire/Explosion/Implosion		HAZARD GRP. CODE 1
REFERENCES FMEA 6.2		AUTHORITY TASK II-3.3

HAZARD DESCRIPTION/ EFFECTS

During return to earth of the propellant module or shuttle orbiter cargo, a hydrogen blowing leak from the propellant module into the cargo bay presents a hazard during entry into the earth atmosphere. When the gas combines with air at a pressure limit of approximately 1 torr it would be within the burning or detonable range. Heat of re-entry is about 2700'R at this time and could provide the source of ignition. The entry heat below 130,000 ft will drop below the spontaneous ignition temperature however static electrical discharge would now be ~~capable of providing ignition source as would mechanical impact.~~

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			CATASTROPHIC

COPIES TO: STRUCTURAL ___ MECHANICAL ___ MATERIALS ___ GSE ___ OTHER ___

AVIONICS ___ PROPULSION ___ VEHICLE SUPPORT ___ FACILITIES ___ PAYLOAD ___ SYS SAFETY X

ACTION RECOMMENDED:

The propellant module should be freed of liquid propellants by dumping with a maximum of 14.7 psia pressure remaining in the tank prior to storage in the cargo bay. Verify by visual means or by leak checks that leakage is in specific tolerance.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				CRITICAL

74

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED ______

HAZARD ANALYSIS

DATE ______

REV ______

END ITEM Propellant Tank Module	SUBSYSTEM Propellant	SUBSYSTEM IDENT NO. 11
OPERATION/PHASE Deorbit		OP. IDENT. NO. D
HAZARD GROUP Fire/Explosion/Implosion		HAZARD GRP. CODE 1
REFERENCES Apollo CSM		AUTHORITY TASK II-3

HAZARD DESCRIPTION/ EFFECTS After the propellant tank module has been returned to the cargo bay, and excess propellants have been dumped to space, residuals will remain in the tank. With the tank leak checked to specification leakage a problem may develop causing explosion during the re-entry phase. Collapse of the insulation (HPI) due to external pressure plus heat from re-entry temperatures will soak the propellant tank. Sloshing on the heated surfaces of residual propellants may cause an immediate rise in tank pressure from flashing to vapor. Where residuals are high and heat leaks great, the increased tank pressure could overpressurize the tank before the vent valve could operate and thus blow the burst disk. Fire and explosion would result from the tank rupture.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			CATASTROPHIC

COPIES TO: STRUCTURAL ____ MECHANICAL ____ MATERIALS ____ GSE ____ OTHER ____

AVIONICS ____ PROPULSION ____ VEHICLE SUPPORT ____ FACILITIES ____ PAYLOAD ____ SYS SAFETY X

ACTION RECOMMENDED:

Liquid propellants should be dumped to a residual quantity such that the sudden application of credible quantities of heat would not flash the residuals into enough vapor that the vent system could not prevent the tank from being overpressurized. Propellant gauging system should be capable of verifying that the quantity of residuals is not excessive.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				MARGINAL

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED ______

OPERATIONAL

HAZARD ANALYSIS

PAGE 1 OF 1

DATE ______

REV ______

END ITEM Shuttle Orbiter	SUBSYSTEM Structural	SUBSYSTEM IDENT NO. 5
OPERATION/PHASE Landing - Perform Final Approach		OP. IDENT. NO. E
HAZARD GROUP Fire/Explosion		HAZARD GRP. CODE 1
REFERENCES FMEA 6.11		AUTHORITY TASK II-3

HAZARD DESCRIPTION/ EFFECTS

The potential for making a rough landing from any cause could lead to Propellant Tank Module or Logistic Element Damage. This could cause loss of propellant containment which could cause fire or explosion. A crash landing or fuel line rupture could cause a similar situation.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			CATASTROPHIC

COPIES TO: STRUCTURAL ____ MECHANICAL ____ MATERIALS ____ GSE ____ OTHER ____

AVIONICS ____ PROPULSION ____ VEHICLE SUPPORT ____ FACILITIES ____ PAYLOAD ____ SYS SAFETY X

ACTION RECOMMENDED:

The landing weight of the module or logistic element should be limited to 40 K pounds. To minimize explosion contribution of logistics element, the structure and attach fittings should be designed with a factor of safety equal to or greater than that of the orbiter.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				CRITICAL

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED ______

OPERATIONAL
HAZARD ANALYSIS

DATE ______

REV ______

END ITEM Orbiter/Logistic Element	SUBSYSTEM Propellant	SUBSYSTEM IDENT NO. 11
OPERATION/PHASE Safing - Deactive Propellant Logistic Element		OP. IDENT. NO. F
HAZARD GROUP Fire/Explosion		HAZARD GRP. CODE 1
REFERENCES FMEA 3.1		AUTHORITY TASK II-3

HAZARD DESCRIPTION/ EFFECTS

An abort which causes a landing at a remote site, with inability to get support equipment into the remote site may cause logistic element tank venting which causes a condition supporting a fire or explosion potential. This presumes the tanks to have residual propellants in them and the tank cannot be removed from the cargo bay.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			CATASTROPHIC

COPIES TO: STRUCTURAL ____ MECHANICAL ____ MATERIALS ____ GSE ____ OTHER ____

AVIONICS ____ PROPULSION ____ VEHICLE SUPPORT ____ FACILITIES ____ PAYLOAD ____ SYS SAFETY X

ACTION RECOMMENDED:

Hydrogen and oxygen vents should be separated as far as possible directed upward and well above such levels that might endanger orbiter and safing crews. The atmospheric exits of the vents should be designed to prevent back-diffusion of atmospheric gases and contamination or increasing the explosive potential of mixed gases in vent lines.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				MARGINAL

77

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED ______

OPERATIONAL
HAZARD ANALYSIS

DATE ______
REV ______

END ITEM Orbiter/Tug	SUBSYSTEM Vehicle Support - Manipulators	SUBSYSTEM IDENT NO. 3
OPERATION/PHASE	Orbital - Configure Shuttle Orbiter for payload deployment operation	OP. IDENT. NO. C
HAZARD GROUP Impact/Explosion		HAZARD GRP. CODE 8, 1
REFERENCES FMEA 3.1A		AUTHORITY TASK II-3

HAZARD DESCRIPTION/ EFFECTS

During preparation for deployment, failure of the manipulator system could drive the arm into the delivery vehicle structure. Where the tanks are partially loaded and pressurized the impact may cause an explosion or penetrate the crew module with loss of ECLSS when the crew module is attached to the Tug. These conditions could damage the Orbiter cargo bay doors and cause loss of crew on re-entry.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			CRITICAL

COPIES TO: STRUCTURAL ____ MECHANICAL ____ MATERIALS ____ GSE ____ OTHER ____

AVIONICS ____ PROPULSION ____ VEHICLE SUPPORT ____ FACILITIES ____ PAYLOAD ____ SYS SAFETY X

ACTION RECOMMENDED:

Energy limiting devices should be incorporated into the manipulator design to limit the energy that can be imparted by the manipulators to a safe level. Consideration should be given to the incorporation of automatic shutdown devices to de-energize the manipulators in the event of a critical failure.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				MARGINAL

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED

OPERATIONAL
HAZARD ANALYSIS

DATE
REV

END ITEM Orbiter/Tug/ Centaur	SUBSYSTEM Propellant	SUBSYSTEM IDENT NO. 11
OPERATION/PHASE Orbital - Configure Shuttle Orbiter for payload deployment operation		OP. IDENT. NO. C
HAZARD GROUP Fire/Explosion/Implosion		HAZARD GRP. CODE 1
REFERENCES FMEA 3.1A		AUTHORITY Project II Task II-3

HAZARD DESCRIPTION/ EFFECTS

Failure of any portion of the OMS to module propellant transfer line due to any cause (fatigue, vibration, rupture, corrosion, etc.) could render the propellant loading operation impossible. If the line failure is not detected prior to transfer of fluids, the fluid could be transferred into the orbiter internal structure. This condition could create conditions for a potential fire or explosion upon re-entry with possible loss of crew.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			CRITICAL

COPIES TO: STRUCTURAL ___ MECHANICAL ___ MATERIALS ___ GSE ___ OTHER ___

AVIONICS ___ PROPULSION ___ VEHICLE SUPPORT ___ FACILITIES ___ PAYLOAD ___ SYS SAFETY X

ACTION RECOMMENDED:

A means should be provided to verify the integry of propellant lines prior to initiating transfer. Should a leak or rupture occur into the orbiter it should be verified that the propellants have dissipated by evaporation or sublimation prior to re-entry of the orbiter.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				MARGINAL

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED ______

OPERATIONAL HAZARD ANALYSIS

DATE ______

REV ______

END ITEM Orbiter/Centaur	SUBSYSTEM Pressurization	SUBSYSTEM IDENT NO. 13
OPERATION/PHASE Orbital - Transfer propellants to delivery vehicle		OP. IDENT. NO. C
HAZARD GROUP Fire/Explosion/Implosion		HAZARD GRP. CODE 1
REFERENCES FMEA 3.2A		AUTHORITY TASK II-3

HAZARD DESCRIPTION/ EFFECTS

Failure of the Centaur LO2 tank vent valve in the open condition while maintaining normal tank pressure on the LH2 tank could cause intermediate bulkhead reversal leading to tank rupture and possible explosion. If this failure is undetected it could cause the hazard of "loss of the orbiter" due to explosive damage to the cargo bay and to cargo bay doors during re-entry.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			CATASTROPHIC

COPIES TO: STRUCTURAL ___ MECHANICAL ___ MATERIALS ___ GSE ___ OTHER ___

AVIONICS ___ PROPULSION ___ VEHICLE SUPPORT ___ FACILITIES ___ PAYLOAD ___ SYS SAFETY X

ACTION RECOMMENDED:

Provide orbiter crew with Centaur tank pressure readout and control. Provide automatic delta pressure correction by venting LH2 tank when LO2 tank pressure approaches the critical limit. If tanks lose pressure during re-entry phase the results could be catastrophic to orbiter and crew.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				CRITICAL

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED ______

OPERATIONAL
HAZARD ANALYSIS

PAGE 1 OF 1
DATE ______
REV ______

END ITEM Orbiter/Tug/Centaur	SUBSYSTEM Propellant	SUBSYSTEM IDENT NO. II
OPERATION/PHASE Orbital - Transfer propellants to delivery vehicle		OP. IDENT. NO. C
HAZARD GROUP Reduced integrity of structure or equipment/explosion		HAZARD GRP. CODE 2, 1
REFERENCES FMEA 3.2A		AUTHORITY Project II, Task II-3

HAZARD DESCRIPTION/ EFFECTS

Failure of the fill and drain disconnect during the transfer operation could cause cryogenic fluids to dump and freeze in the cargo bay. In large quantities this ice (LH2) may be retained within the cargo bay and if not known to the orbiter crew or realizing an abort is required, should the crew terminate transfer operations, close the cargo bay doors and attempt return to earth, the ice could vaporize and cause an explosion within the bay during re-entry. This failure of the disconnect could be caused by improper ground installation.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			CATASTROPHIC

COPIES TO: STRUCTURAL ___ MECHANICAL ___ MATERIALS ___ GSE ___ OTHER ___

AVIONICS ___ PROPULSION ___ VEHICLE SUPPORT ___ FACILITIES ___ PAYLOAD ___ SYS SAFETY X

ACTION RECOMMENDED:

A means should be incorporated into transfer lines to verify that a leak-tight connection has been made prior to initiating propellant flow. A visual check to verify that cargo bay is free of solid propellants should be made prior to committing to re-entry.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				MARGINAL

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED ______

INTEGRATION
HAZARD ANALYSIS

DATE ______
REV ______

END ITEM Orbiter/Tug/Centaur	SUBSYSTEM Propellant	SUBSYSTEM IDENT NO. II
OPERATION/PHASE Orbital - Transfer propellants to delivery vehicle		OP. IDENT. NO. C
HAZARD GROUP Fire/Explosion/Implosion		HAZARD GRP. CODE 1
REFERENCES FMEA 3.2A GDC-BM270-024		AUTHORITY Project II Task II-3

HAZARD DESCRIPTION/ EFFECTS

An explosive hazard exists from locked up cryogens in the line segment between the transfer valve and OMS propellant loading valve. This can be expected as a result of failure to position the three-way propellant transfer valves to the vent position. The explosion of the line due to propellant expansion would occur within the orbiter and create an additional hazard of fire in the event that fluid release was confined and subjected to heat of re-entry.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			CATASTROPHIC

COPIES TO: STRUCTURAL ___ MECHANICAL ___ MATERIALS ___ GSE ___ OTHER ___

AVIONICS ___ PROPULSION ___ VEHICLE SUPPORT ___ FACILITIES ___ PAYLOAD ___ SYS SAFETY X

ACTION RECOMMENDED:

Relief capability should be provided on all sections of line where it is possible to trap propellants.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				MARGINAL

82

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED ______

INTERFACE
HAZARD ANALYSIS

PAGE 1 OF 1

DATE ______

REV ______

END ITEM Orbiter/Tug/Centaur	SUBSYSTEM Propellant	SUBSYSTEM IDENT NO. 11
OPERATION/PHASE Orbital - Transfer propellants to delivery vehicle		OP. IDENT. NO. C
HAZARD GROUP Reduced integrity of structure or equipment		HAZARD GRP. CODE 2
REFERENCES FMEA 3.2A		AUTHORITY Project II Task II-3

HAZARD DESCRIPTION/ EFFECTS

Failure of the propellant orientation device in the OMS tank could cause improper orientation of the fluids at the tank outlet delivering two-phase flow to the transfer pump inlet. This condition creates the hazard of pump cavitation and loss of control of fluids transferred (quantity) which in the extreme case could cause pump failure and mission degradation, respectively.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			CRITICAL

COPIES TO: STRUCTURAL ___ MECHANICAL ___ MATERIALS ___ GSE ___ OTHER ___

AVIONICS ___ PROPULSION ___ VEHICLE SUPPORT ___ FACILITIES ___ PAYLOAD ___ SYS SAFETY XX

ACTION RECOMMENDED:

The propellant transfer pump should be designed to be capable of handling two-phase flow. Flow measuring devices should measure the mass, not volume, of transferred fluids.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				MARGINAL

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED ______

OPERATIONAL HAZARD ANALYSIS

PAGE 1 OF 1

DATE ______

REV ______

END ITEM Orbiter/Tug/Centaur	SUBSYSTEM Propellant	SUBSYSTEM IDENT NO. 11
OPERATION/PHASE Orbital - Transfer propellants to delivery vehicle		OP. IDENT. NO. C
HAZARD GROUP Fire/Explosion		HAZARD GRP. CODE 1
REFERENCES FMEA 3.2A		AUTHORITY Task II-3

HAZARD DESCRIPTION/ EFFECTS

Internal failure of the auxiliary transfer pump, due to cavitation, contamination, or misalignment, could create a pump explosion which would damage the immediate area by fragmentation. Fragments could penetrate the tug or Centaur propellant tanks which could cause cryogenic fluids to spill into the area of the cargo bay. In attempting to take abort action the ice LH2 and LO2 may form a mixture which is explosive if not dissipated prior to re-entry.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			CRITICAL

COPIES TO: STRUCTURAL ___ MECHANICAL ___ MATERIALS ___ GSE ___ OTHER ___

AVIONICS ___ PROPULSION ___ VEHICLE SUPPORT ___ FACILITIES ___ PAYLOAD ___ SYS SAFETY X

ACTION RECOMMENDED:

All rotating machinery should be provided with fragmentation shields that will contain the parts of such machinery should it explode. Provide screens ahead of the pump to minimize damage to the pump from contamination.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				MARGINAL

84

CONTRACT ~~NAS8-27692~~

LOCATION/SITE INVOLVED ______

OPERATIONAL HAZARD ANALYSIS

PAGE 1 OF 1
DATE ______
REV ______

END ITEM Orbiter/Down Module	SUBSYSTEM Vehicle Support ~~– Manipulators~~	SUBSYSTEM IDENT NO. 3
OPERATION/PHASE Orbital - Transfer down module to orbiter cargo bay		OP. IDENT. NO. C
HAZARD GROUP Impact, Implosion/Explosion		HAZARD GRP. CODE 8.1
REFERENCES FMEA 3.3A FMEA 3.4A		AUTHORITY Project II, Task II-3

HAZARD DESCRIPTION/ EFFECTS

Manipulator failure or human error in operating the manipulators could align the down module such that it strikes the cargo bay doors, cargo bay walls, or the attach points and supports for the module. If excessive speed is involved the impact could create a penetration which could cause loss of module pressurization. If undetected, the tank could implode upon re-entry with the additional possible hazard of explosion in the cargo bay.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			CRITICAL

COPIES TO: STRUCTURAL ____ MECHANICAL ____ MATERIALS ____ GSE ____ OTHER ____

AVIONICS ____ PROPULSION ____ VEHICLE SUPPORT ____ FACILITIES ____ PAYLOAD ____ SYS SAFETY X

ACTION RECOMMENDED:

Energy-limiting devices should be incorporated into the manipulator system to limit the energy/velocity that can be imparted by the manipulators to a safe level. Tanks should not be de-orbited in the shuttle unless the tank pressure can be verified to be equal to or greater than atmospheric pressure.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				MARGINAL

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED ______

OPERATIONAL HAZARD ANALYSIS

DATE ______

REV ______

END ITEM Orbiter/Tug	SUBSYSTEM Propulsion	SUBSYSTEM IDENT NO. 2
OPERATION/PHASE Orbital - Transfer down module to Orbiter cargo bay		OP. IDENT. NO. C
HAZARD GROUP Impact, Loss of habitable environment		HAZARD GRP. CODE 8, 10
REFERENCES FMEA 3.3A		AUTHORITY Project II, Task II-3

HAZARD DESCRIPTION/ EFFECTS

Upon separation of the down module, the tug may become unstable requiring stabilization system actuation. Improper operational techniques or control failure to shut down RCS operation could cause the tug to impact the load suspended on the manipulators. This condition could lead to possible penetration of the manned crew module structure if on the tug, causing loss of habitable environment.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			CRITICAL

COPIES TO: STRUCTURAL ____ MECHANICAL ____ MATERIALS ____ GSE ____ OTHER ____

AVIONICS ____ PROPULSION ____ VEHICLE SUPPORT ____ FACILITIES ____ PAYLOAD ____ SYS SAFETY XX

ACTION RECOMMENDED:

Redundancy should be incorporated into ACS controls to insure operation during critical maneuvers. The control pilot should be trained on simulators that closely approximate actual operations to minimize operator error.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				MARGINAL

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED ______

OPERATIONAL
HAZARD ANALYSIS

DATE ______
REV ______

END ITEM Orbiter Down Module	SUBSYSTEM Structural/Pressurization	SUBSYSTEM IDENT NO. 5, 13
OPERATION/PHASE Deorbit/Orbital - Transfer down module to orbiter cargo bay		OP. IDENT. NO. C, D
HAZARD GROUP Fire/Explosion/Implosion		HAZARD GRP. CODE 1
REFERENCES FMEA 3.3A		AUTHORITY Task II-3

HAZARD DESCRIPTION/ EFFECTS A hazard could be created when the down module has been subjected to the following conditions: (1) Has been vented to vacuum ambient pressure and then locked up, or (2) has been pressurized and lost its pressure either by system leak or meteoroid penetration. Condition 1 could have all indications of an empty tank but have ice formation left within the tank which could then cause venting within the cargo bay during entry. Condition 2 would lead to implosion of the tank during earth re-entry. Either of these conditions, if not detected, could cause fire/explosion/implosion within the cargo bay during re-entry.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			CATASTROPHIC

COPIES TO: STRUCTURAL ___ MECHANICAL ___ MATERIALS ___ GSE ___ OTHER ___

AVIONICS ___ PROPULSION ___ VEHICLE SUPPORT ___ FACILITIES ___ PAYLOAD ___ SYS SAFETY X

ACTION RECOMMENDED:

Propellant modules should not be returned by shuttle unless it is verified to be pressurized to at least one atmopshere, and must not vent or leak propellant into the cargo bay. If module cannot be pressurized it must be verified that no propellant remain in the tank and vents must be open and sized to prevent negative pressures upon re-entry.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				MARGINAL

CONTRACT ~~NAS8-27692~~

LOCATION/SITE INVOLVED ______

OPERATIONAL HAZARD ANALYSIS

PAGE 1 OF 1

DATE ______

REV ______

END ITEM Tug/OPD/Propellant Module	SUBSYSTEM Propellant	SUBSYSTEM IDENT NO. 11
OPERATION/PHASE Orbital - Rendezvous with OPD		OP. IDENT. NO. D
HAZARD GROUP Impact		HAZARD GRP. CODE 8
REFERENCES FMEA 3.4A FMEA 4.2A		AUTHORITY Task II-3

HAZARD DESCRIPTION/ EFFECTS

Inaccuracies in quantity of loaded propellants in the tug or excessive use rate could deplete the propellants from the tug main tanks. In this condition the RCS will fail to operate. If the depletion occurs when the tug/module is moving into docking position the full force of the uncontrolled configuration would impact into the OPD or orbiter as no RCS tanks are held in reserve. The tug would thus be adrift in an uncontrolled mode.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			CATASTROPHIC

COPIES TO: STRUCTURAL ____ MECHANICAL ____ MATERIALS ____ GSE ____ OTHER ____

AVIONICS ____ PROPULSION ____ VEHICLE SUPPORT ____ FACILITIES ____ PAYLOAD ____ SYS SAFETY X

ACTION RECOMMENDED:

A means should be provided for accurately determining the amount of propellants available to maintain attitude control. Prior to initiating a maneuver in which attitude control is critical it should be verified, either manually or automatically, that sufficient propellants are available to complete the maneuver.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				CRITICAL

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED ______

OPERATIONAL
HAZARD ANALYSIS

DATE ______

REV ______

END ITEM Orbiter/Tug/Centaur	SUBSYSTEM Propulsion	SUBSYSTEM IDENT NO. 2
OPERATION/PHASE Orbital - Transfer delivery vehicle down for maintenance		OP. IDENT. NO. C
HAZARD GROUP Impact, loss of attitude control		HAZARD GRP. CODE 8, 9
REFERENCES FMEA 3.4A		AUTHORITY TASK II-3

HAZARD DESCRIPTION/ EFFECTS

A hazard is created where, during rendezvous with the orbiter, the Tug vehicle fails to stabilize. This failure would operationally restrict the shuttle from capturing the ground based tug for earth return, where the instability was excessive. In the case of the tug with an attached crew module, the loss of stabilization could impair the safety of the crew. In attempting to make an emergency capture of the tug, if the crew was unable to operate effectively, the vehicle could impact the shuttle.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			CRITICAL

COPIES TO: STRUCTURAL ____ MECHANICAL ____ MATERIALS ____ GSE ____ OTHER ____

AVIONICS ____ PROPULSION ____ VEHICLE SUPPORT ____ FACILITIES ____ PAYLOAD ____ SYS SAFETY X

ACTION RECOMMENDED:

Redundancy should be incorporated into ACS controls to insure operation during critical maneuvers. The control pilot should be trained on simulators that closely approximate actual operations to minimize operator error. No attempts should be made to rendezvous and dock with an unstable vehicle.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				MARGINAL

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED ______

INTERFACE
HAZARD ANALYSIS

DATE ______

REV ______

END ITEM	SUBSYSTEM	SUBSYSTEM IDENT NO.
Orbiter/Down Module	Mechanical	4
OPERATION/PHASE: Orbiter - Transfer down module to orbiter cargo bay		OP. IDENT. NO.
HAZARD GROUP: Fire/Explosion/Implosion		HAZARD GRP. CODE: 1
REFERENCES: FMEA 3.3A FMEA 3.4A		AUTHORITY: Task II-3

HAZARD DESCRIPTION/ EFFECTS Down modules will not always be the same and the attach fittings, supports, diameters, etc., will require reconfiguring to accommodate the down module within the cargo bay. It can be postulated that either human error or configuration mismatch will cause a hazard wherein the attach fitting latches fail to latch properly. Under this condition the module could shift within the cargo bay, projections penetrate the tank walls, and create an explosion environment during re-entry.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			CATASTROPHIC

COPIES TO: STRUCTURAL ____ MECHANICAL ____ MATERIALS ____ GSE ____ OTHER ____

AVIONICS ____ PROPULSION ____ VEHICLE SUPPORT ____ FACILITIES ____ PAYLOAD ____ SYS SAFETY X

ACTION RECOMMENDED:

Attach fittings should be pre-positioned in the cargo bay while orbiter is on the ground. The position of the fittings should be verified by jigs, fixtures or other devices and all latches verified to be operational. Repositioning of attach fittings with EVA while in orbit is to be avoided. Verification of attachment, visual or electrical, should be made prior to de-orbit.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				MARGINAL

90

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED

OPERATIONAL HAZARD ANALYSIS

DATE

REV

END ITEM Orbiter/Tug/Agena/Centaur/FW-4S	SUBSYSTEM Vehicle Support - Manipulator	SUBSYSTEM IDENT NO. 3
OPERATION/PHASE Orbital - Deploy Delivery Vehicle		OP. IDENT. NO. C
HAZARD GROUP Fsre/Explosion/Implosion		HAZARD GRP. CODE 1
REFERENCES FMEA 3.6A FMEA 3.8A		AUTHORITY Task II-3

HAZARD DESCRIPTION/ EFFECTS Failure of one attach point to release creates a hazard wherein the manipulator may be used to free the vehicle. In attempting to free the vehicle if the stressing by the manipulator is excessive the grain in the FW-4S may crack causing an explosion at ignition of the engine. EVA would be required for freeing the attach point on the Tug/Centaur, which in turn may cause the crew member to be injured if the load shifted upon release, or if the cryogenic tanks vented into the cargo bay.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			CRITICAL

COPIES TO: STRUCTURAL ____ MECHANICAL ____ MATERIALS ____ GSE ____ OTHER ____

AVIONICS ____ PROPULSION ____ VEHICLE SUPPORT ____ FACILITIES ____ PAYLOAD ____ SYS SAFETY ____

ACTION RECOMMENDED:

Procedures or techniques should be implemented to insure that manipulator action is not initiated until latches are free.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				MARGINAL

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED ______

OPERATIONAL HAZARD ANALYSIS

DATE ______

REV ______

END ITEM Orbiter/PPS/ Propellant Module	SUBSYSTEM Vehicle Support - Manipulators	SUBSYSTEM IDENT NO. 3
OPERATION/PHASE Orbital - Deploy delivery vehicle		OP. IDENT. NO. C
HAZARD GROUP Impact		HAZARD GRP. CODE 8
REFERENCES FMEA 3.6A FMEA 3.8A		AUTHORITY Project II, Task II-3

HAZARD DESCRIPTION/ EFFECTS Erratic action of the manipulators while withdrawing the Tug, Centaur, or Propellant Module out of the cargo bay could create an impact hazard between the vehicle and the cargo bay walls. This is created by accomplishing the withdrawal with two manipulators separated by the cargo bay width. Erratic operation of one of the manipulators could cause centerline misalignment with the cargo bay walls, coupled with sloshing effects of the propellants in the delivery vehicles tanks, which could cause the delivery vehicle to oscillate about the CG. The amplitude of the oscillations could cause impact by cocking as the load is withdrawn.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			CRITICAL

COPIES TO: STRUCTURAL ____ MECHANICAL ____ MATERIALS ____ GSE ____ OTHER ____

AVIONICS ____ PROPULSION ____ VEHICLE SUPPORT ____ FACILITIES ____ PAYLOAD ____ SYS SAFETY X

ACTION RECOMMENDED:

Provide a means to lock the movement of the two manipulators together so that non-simulataneous movement is prohibited.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				MARGINAL

92

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED

OPERATIONAL
HAZARD ANALYSIS

PAGE 1 OF 1
DATE
REV

END ITEM Orbiter	SUBSYSTEM Vehicle Support - Manipulators	SUBSYSTEM IDENT NO. 3
OPERATION/PHASE Orbital - Deploy Delivery Vehicle		OP. IDENT. NO. C
HAZARD GROUP Reduced integrity of Structure or Equipment		HAZARD GRP. CODE 2
REFERENCES FMEA 3.6A FMEA 3.8A FMEA 3.9A		AUTHORITY Project II, Task II-3

HAZARD DESCRIPTION/ EFFECTS The failure of the TV and/or floodlighting on the manipulator arm(s) renders the system unsafe for use, as the control operator has no visibility for his decision making process. However, if only one set of aids are lost the other arm will be functional. Attempting to operate with this reduced capability could create hazards. These are impact hazards created when the field of view on one arm cannot see the entire operating area. Attempting to hold the load with the disabled arm, while releasing the load with the other (good) arm to take a "look" could initiate the impact.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			CRITICAL

COPIES TO: STRUCTURAL ____ MECHANICAL ____ MATERIALS ____ GSE ____ OTHER ____

AVIONICS ____ PROPULSION ____ VEHICLE SUPPORT ____ FACILITIES ____ PAYLOAD ____ SYS SAFETY X

ACTION RECOMMENDED:

Operator training and strict procedural controls should be implemented to stop operations when visual contact has been lost or reduced. Redundancy of critical operating aids shall be mandatory.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				MARGINAL

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED ____

OPERATIONAL
HAZARD ANALYSIS

PAGE 1 OF 1
DATE ____
REV ____

END ITEM Orbiter/Tug/Centaur	SUBSYSTEM Avionics	SUBSYSTEM IDENT NO. 1
OPERATION/PHASE Orbital - Deploy Delivery Vehicle		OP. IDENT. NO. C
HAZARD GROUP Disturbance, Impact		HAZARD GRP. CODE 12, 8
REFERENCES FMEA 3.6A FMEA 3.8A		AUTHORITY Task II-3

HAZARD DESCRIPTION/ EFFECTS Under conditions where the delivery vehicle is partially out of the orbiter cargo bay and suspended on the manipulator arms, failure in the stabilization control system or human error, which activates the RCS could cause the load to become unstable due to flexing of the manipulator arms and to mass reaction to the orbiter movement. This coupled with the sloshing of the propellants in the delivery vehicle could delay the mission until attitude and stabilization are controlled.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			CRITICAL

COPIES TO: STRUCTURAL ____ MECHANICAL ____ MATERIALS ____ GSE ____ OTHER ____

AVIONICS ____ PROPULSION ____ VEHICLE SUPPORT ____ FACILITIES ____ PAYLOAD ____ SYS SAFETY X

ACTION RECOMMENDED:

Critical control functions in the RCS should have redundant elements to minimize failure. Operators should be trained for the functions they are to perform and should operate from detailed procedures or checklists to minimize human error.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				MARGINAL

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED ______

OPERATIONAL
HAZARD ANALYSIS

DATE ______

REV ______

END ITEM Orbiter/Tug/Centaur	SUBSYSTEM Propellant	SUBSYSTEM IDENT NO. 13
OPERATION/PHASE Orbital - Deploy Delivery Vehicle		OP. IDENT. NO. C
HAZARD GROUP Contamination		HAZARD GRP. CODE 3
REFERENCES FMEA 3.6A		AUTHORITY TASK II-3

HAZARD DESCRIPTION/ EFFECTS In the process of deploying the Tug or Centaur it is necessary to separate the vehicles from the orbiter interfaces at the provided QD's. A hazard could be created when the deployment process becomes out of alignment, with the attached Q.D. Through seizure of the QD due to particles or chips, it may fail to release and in so doing the orbiter or delivery vehicle side of the disconnect may be destroyed by the continued movement of the deployment separation process. This could lead to line rupture causing cryogens to slug the cargo bay area causing damage to the attached payload.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			CATASTROPHIC

COPIES TO: STRUCTURAL ____ MECHANICAL ____ MATERIALS ____ GSE ____ OTHER ____

AVIONICS ____ PROPULSION ____ VEHICLE SUPPORT ____ FACILITIES ____ PAYLOAD ____ SYS SAFETY X

ACTION RECOMMENDED:

Guides or alignment fixtures should be provided that will permit separation without binding the Q.D. Screens or filters should be provided that will minimize damage to critical components because of contamination.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				MARGINAL

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED ______

OPERATIONAL

HAZARD ANALYSIS

DATE ______

REV ______

END ITEM Orbiter	SUBSYSTEM Avionics/Human	SUBSYSTEM IDENT NO. 1, 12
OPERATION/PHASE Orbital - Separate From Delivery Vehicle		OP. IDENT. NO. C
HAZARD GROUP Impact		HAZARD GRP. CODE 8
REFERENCES FMEA 3.7A FMEA 3.10A		AUTHORITY Project II, Task II-3

HAZARD DESCRIPTION/ EFFECTS Failure of the orbiter Auxiliary Propulsion System control or human error in control selection, which causes a rotational movement about the orbiter pitch axis could create an impact hazard if occurring at the initial stage of separation. Failure of the RCS engines to stabilize the orbiter could also create the rotational movement. The movement could reasonably be expected to cause impact between the orbiter and deployed delivery vehicle. The impact could cause injury to the orbiter crew if not aware of the impending shock.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			CRITICAL

COPIES TO: STRUCTURAL ____ MECHANICAL ____ MATERIALS ____ GSE ____ OTHER ____

AVIONICS ____ PROPULSION ____ VEHICLE SUPPORT ____ FACILITIES ____ PAYLOAD ____ SYS SAFETY X

ACTION RECOMMENDED:

Critical control functions in the Auxiliary Propulsion System should have redundant elements to minimize failure. Operators should be trained for the functions they are to perform and should operate from detailed procedures or checklists to minimize human error.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				CRITICAL

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED ______

ORBITER
HAZARD ANALYSIS

PAGE 1 OF 1
DATE ______
REV ______

END ITEM Orbiter/Tug/Centaur	SUBSYSTEM Avionics	SUBSYSTEM IDENT NO. I
OPERATION/PHASE Orbital - Dock payload module to delivery vehicle		OP. IDENT. NO. C
HAZARD GROUP Impact		HAZARD GRP. CODE 8
REFERENCES FMEA 3.9A		AUTHORITY Task II-3

HAZARD DESCRIPTION/ EFFECTS Failure of the Orbiter to stabilize (due to CG shift and inertia of module) with the payload suspended on the manipulators could create a hazard if docking of the payload to the Tug or Centaur is attempted before the configuration is stabilized. Instability of the coupling between the orbiter, manipulators and payload module could cause the payload to oscillate due to manipulator arm flexure. An attempt to dock would cause impact damage to the docking ring due to misalignment.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			CRITICAL

COPIES TO: STRUCTURAL ____ MECHANICAL ____ MATERIALS ____ GSE ____ OTHER ____

AVIONICS ____ PROPULSION ____ VEHICLE SUPPORT ____ FACILITIES ____ PAYLOAD ____ SYS SAFETY X

ACTION RECOMMENDED:

Energy limiting devices should be incorporated into the manipulator system to prevent sudden application of loads to initiate oscillations. Propellant slosh baffles should be incorporated in propellant tanks to be handled by the manipulators. Oscillation dampening devices should be incorporated into manipulator system. Procedural limitations should be imposed to prevent any attempts to dock an oscillating module.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				CRITICAL

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED ______

OPERATIONAL
HAZARD ANALYSIS

PAGE 1 OF 1
DATE ______
REV ______

END ITEM Orbiter/Tug	SUBSYSTEM Avionics	SUBSYSTEM IDENT NO. 1
OPERATION/PHASE Orbital - Dock payload module to delivery vehicle		OP. IDENT. NO. C
HAZARD GROUP Impact		HAZARD GRP. CODE 8
REFERENCES FMEA 3.9A		AUTHORITY Project II, Task II-3

HAZARD DESCRIPTION/ EFFECTS The Tug which has a crew module attached will be in communication with the Orbiter and ground net. Loss of communication between them during the payload docking operation could create a hazard causing impact of the vehicles in the event the Tug crew attempted to accomplish alignment and docking, while the orbiter crew thought they were in control of the operation, without a specific contingency plan. This could also happen in the unmanned tug mode if communications were lost between the Orbiter and ground net without preplanned contingency definition.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			CRITICAL

COPIES TO: STRUCTURAL ____ MECHANICAL ____ MATERIALS ____ GSE ____ OTHER ____

AVIONICS ____ PROPULSION ____ VEHICLE SUPPORT ____ FACILITIES ____ PAYLOAD ____ SYS SAFETY X

ACTION RECOMMENDED: Critical communications circuits should have back-up capability. During critical operations such as docking, operational controls should be maintained in accordance with procedures or checklists. These procedures or checklists should contain pre-planned emergency or back-out procedures to cover securing or safing actions to be taken when credible accidents occur, such as the loss of communications. It must be clear which crew has command control at all times.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				MARGINAL

98

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED

HAZARD ANALYSIS

PAGE ____ OF ____

DATE ____

REV ____

END ITEM Orbiter/Tug	SUBSYSTEM Avionics	SUBSYSTEM IDENT NO. 1
OPERATION/PHASE] Orbital - Dock payload module to delivery vehicle		OP. IDENT. NO. C
HAZARD GROUP Impact		HAZARD GRP. CODE 8
REFERENCES FMEA 3.9A		AUTHORITY Project II, Task II-3

HAZARD DESCRIPTION/ EFFECTS Overcontrol of the orbiter/payload, at the final closure for docking, in the pitch or yaw plane of the payload docking adapter centerline could cause impact damage to the structure. Under normal design closure rates this is no problem, however, if excessive closure velocities are involved the impact could damage/destroy the docking ring structure, impact the line interconnect fixture, or damage the module's insulation.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			Critical

COPIES TO: STRUCTURAL ____ MECHANICAL ____ MATERIALS ____ GSE ____ OTHER ____

AVIONICS ____ PROPULSION ____ VEHICLE SUPPORT ____ FACILITIES ____ PAYLOAD ____ SYS SAFETY X

ACTION RECOMMENDED:

The final closing velocity/attitude of the docking maneuver should be automatically controlled to limit impact energy to safe limits.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				Critical

99

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED ____

OPERATIONAL HAZARD ANALYSIS

PAGE 1 OF 1

DATE ____

REV ____

END ITEM Orbiter/Tug	SUBSYSTEM Mechanical	SUBSYSTEM IDENT NO. 4
OPERATION/PHASE Orbital - Dock payload module to delivery vehicle		OP. IDENT. NO. C
HAZARD GROUP Distrubance		HAZARD GRP. CODE 12
REFERENCES FMEA 3.9A		AUTHORITY TASK II-3

HAZARD DESCRIPTION/ EFFECTS It is possible that during an attempted docking, an alignment problem could be encountered to the extent that one docking capture latch may engage while the remainder would not. The occurrence of the capture may not be apparent until separation for another try is attempted. Under this condition the action of the RCS may impart a disturbance into the configuration which makes stabilization of the configuration difficult or impossible.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			CRITICAL

COPIES TO: STRUCTURAL ____ MECHANICAL ____ MATERIALS ____ GSE ____ OTHER ____

AVIONICS ____ PROPULSION ____ VEHICLE SUPPORT ____ FACILITIES ____ PAYLOAD ____ SYS SAFETY X

ACTION RECOMMENDED:

Provide a positive means to verify that latches are engaged and locked, or unlatched and free as operational phase dictates. A back-up means of capture latch release should be provided in case the primary means fails.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				MARGINAL

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED

OPERATIONAL
HAZARD ANALYSIS

DATE

REV

END ITEM OPD/Tug/ Propellant Module	SUBSYSTEM Avionics/Human	SUBSYSTEM IDENT NO. 1, 12
OPERATION/PHASE Orbital - Rendezvous with OPD		OP. IDENT. NO. C
HAZARD GROUP Impact		HAZARD GRP. CODE 8
REFERENCES FMEA 4.2A		AUTHORITY Project II, Task II-3

HAZARD DESCRIPTION/ EFFECTS

Failure of the Avionics system to shut down the RCS through loss of ground data link or ground control error, could drive the Tug with propellant module attached into the OPD with excessive velocity, causing impact. This hazard would result in loss of the mission with potential loss of the OPD to rupture and explosion of tankage.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			CATASTROPHIC

COPIES TO: STRUCTURAL ____ MECHANICAL ____ MATERIALS ____ GSE ____ OTHER ____

AVIONICS ____ PROPULSION ____ VEHICLE SUPPORT ____ FACILITIES ____ PAYLOAD ____ SYS SAFETY X

ACTION RECOMMENDED:

The final closing velocity/attitude of the rendezvous maneuver should be locally, and automatically controlled with redundant communications between logistics elements to limit impact energy to safe limits.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				CRITICAL

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED ____

OPERATIONAL
HAZARD ANALYSIS

PAGE 1 OF 1
DATE ____
REV ____

END ITEM Tug/Propellant Module	SUBSYSTEM Structural	SUBSYSTEM IDENT NO. 5
OPERATION/PHASE Orbital - Rendezvous with OPD		OP. IDENT. NO. C
HAZARD GROUP Impact		HAZARD GRP. CODE 8
REFERENCES FMEA 4.2A, Ref. 29 of Literature Review		AUTHORITY Task II-3

HAZARD DESCRIPTION/ EFFECTS The hazard by impact of a meteoroid in critical areas is an inherent hazard to space operations. The magnitude of this hazard will depend on the size of the meteoroid and the effectiveness of the meteoroid shield. Meteoroids in excess of 1 gm mass and 15 mm in diameter, may be expected to penetrate the structure, release energy within the structure and damage equipment or start fires in local areas. Loss of communications negates the capability to rendezvous and dock and causes loss of mission.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			CATASTROPHIC

COPIES TO: STRUCTURAL ____ MECHANICAL ____ MATERIALS ____ GSE ____ OTHER ____

AVIONICS ____ PROPULSION ____ VEHICLE SUPPORT ____ FACILITIES ____ PAYLOAD ____ SYS SAFETY X

ACTION RECOMMENDED: To counter the effects of the impact of meteoroids of intermediate size (large enough to penetrate meteoroid shield) the crew should be provided with emergency patches to enable them to maintain life support until rescue or until suits can be donned to await rescue. The impact in critical areas with meteors of larger than intermediate size can be expected to be catastrophic.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				CATASTROPHIC

102

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED

OPERATIONAL HAZARD ANALYSIS

PAGE 1 OF 1

DATE

REV

END ITEM	SUBSYSTEM	SUBSYSTEM IDENT NO.
Tug Propellant Module	Structural	5
OPERATION/PHASE: Orbital - Rendezvous with OPD		OP. IDENT. NO.: C
HAZARD GROUP: Impact		HAZARD GRP. CODE: 8
REFERENCES: FMEA 4.2A		AUTHORITY: TASK II-3

HAZARD DESCRIPTION/ EFFECTS

The inability of ground control to locate space debris and command the Space Base Tug trajectory change, could subject the vehicle to the hazard of impact with the space debris. Where large debris is encountered it could be reasonably expected to do structural damage causing loss of the mission. Small debris will be effectively stopped by the meteoroid shielding.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			CATASTROPHIC

COPIES TO: STRUCTURAL ____ MECHANICAL ____ MATERIALS ____ GSE ____ OTHER ____

AVIONICS ____ PROPULSION ____ VEHICLE SUPPORT ____ FACILITIES ____ PAYLOAD ____ SYS SAFETY X

ACTION RECOMMENDED:

Conduct a trade study to determine the need for radar aboard the Tug that will track local space debris with greater resolution and transmit data to ground control for action or apply data to automatic corrective action aboard the Tug.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				CATASTROPHIC

103

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED ____

OPERATIONAL HAZARD ANALYSIS

PAGE 1 OF 1
DATE ____
REV ____

END ITEM Tug/OPD/ Propellant Module	SUBSYSTEM Avionics	SUBSYSTEM IDENT NO. 1
OPERATION/PHASE Orbital - Rendezvous With OPD		OP. IDENT. NO. C
HAZARD GROUP Loss Of Communication		HAZARD GRP. CODE 11
REFERENCES FMEA 4.2A		AUTHORITY TASK II-3

HAZARD DESCRIPTION/ EFFECTS Failure of the ground data link up/down to communicate operational commands to the Space Based Tug renders the vehicle incapable of completing the mission. Feedback from the Tug to ground if lost also creates hazards. Depending on the mode of operation at time of failure the loss could result in no hazard or a catastrophic impact. The orbiter crew may provide control if the ground net cannot communicate with the orbiter.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			CATASTROPHIC

COPIES TO: STRUCTURAL ____ MECHANICAL ____ MATERIALS ____ GSE ____ OTHER ____

AVIONICS ____ PROPULSION ____ VEHICLE SUPPORT ____ FACILITIES ____ PAYLOAD ____ SYS SAFETY X

ACTION RECOMMENDED:

Critical communications circuits should have back-up capability so that data transmission is not interrupted because of the loss of a single system.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				MARGINAL

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED ____

OPERATIONAL
HAZARD ANALYSIS

PAGE 1 OF 1
DATE ____
REV ____

END ITEM Tug/OPD	SUBSYSTEM Structural	SUBSYSTEM IDENT NO. 5
OPERATION/PHASE Orbital - Dock Propellant Module to OPD		OP. IDENT. NO. C
HAZARD GROUP Impact		HAZARD GRP. CODE 8
REFERENCES FMEA 4.3A		AUTHORITY TASK II-3

HAZARD DESCRIPTION/ EFFECTS Failure to brake the Space Based Tug after closure burn could exceed the limits for closure velocity and cause structural damage in the docking port area due to the energy involved. This could be expected to damage the docking ring, structural support for the ring and if not correctly aligned could damage the line interconnect fixture. The possibility of the structural damage causing propellant module tank leakage is also a hazard to the mission. The impact may be accelerated by the sloshing fluids.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			CRITICAL

COPIES TO: STRUCTURAL ____ MECHANICAL ____ MATERIALS ____ GSE ____ OTHER ____

AVIONICS ____ PROPULSION ____ VEHICLE SUPPORT ____ FACILITIES ____ PAYLOAD ____ SYS SAFETY X

ACTION RECOMMENDED:

The final closing velocity/attitude of the docking maneuver should be automatically controlled (with Manual override) to limit impact energy to design tolerance. RCS controls should have back-up capability to be used in case the primary controls fail.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				MARGINAL

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED

OPERATIONAL
HAZARD ANALYSIS

DATE

REV

END ITEM Tug/OPD	SUBSYSTEM Avionics	SUBSYSTEM IDENT NO. 1
OPERATION/PHASE Orbital - Dock propellant module to OPD		OP. IDENT. NO. C
HAZARD GROUP Loss Of Communications		HAZARD GRP. CODE 11
REFERENCES FMEA 4.3A		AUTHORITY Project II, Task II-3

HAZARD DESCRIPTION/ EFFECTS The effectiveness of the docking aids in the remote controlled docking of the Space Based Tug to the OPD has to assure intelligence is available to the control operator. The loss of the TV data from a failed camera or the loss of the data link during docking creates a hazard leading to possible impact of the vehicles. This hazard is restricted to the docking condition where the failure occurs when the Tug and propellant module are closer than the sum of the Tug, propellant module and the OPD radius of rotation in the same plane.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			CRITICAL

COPIES TO: STRUCTURAL ___ MECHANICAL ___ MATERIALS ___ GSE ___ OTHER ___

AVIONICS ___ PROPULSION ___ VEHICLE SUPPORT ___ FACILITIES ___ PAYLOAD ___ SYS SAFETY X

ACTION RECOMMENDED:

When any critical docking aid is lost during the docking maneuver, back-out procedures should be implemented to safely terminate the operations in progress until repairs can be made to the docking aids.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				MARGINAL

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED ______

OPERATIONAL

HAZARD ANALYSIS

PAGE 1 OF 1

DATE ______

REV ______

END ITEM OPD	SUBSYSTEM Avionics	SUBSYSTEM IDENT NO. 1
OPERATION/PHASE Orbital - Dock Propellant Module to OPD		OP. IDENT. NO. C
HAZARD GROUP Loss Of Attitude Control		HAZARD GRP. CODE 9
REFERENCES FMEA 4.3A		AUTHORITY Project II, Task II-3

HAZARD DESCRIPTION/ EFFECTS Failure of the stabilization system of the OPD to maintain a stable docking interface will delay the mission. There exists a hazard in the case where an attempt is made by the ground control to dock under this condition. This attempt could be expected to cause misalignment of the docking ring with possible impact damage thereto. The misalignment could further impart energy during the impact into the OPD causing disturbance to propogate through the OPD causing sloshing and further instability. Should a capture latch lock into the Tug/Module the combination could fail structurally.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			CATASTROPHIC

COPIES TO: STRUCTURAL ____ MECHANICAL ____ MATERIALS ____ GSE ____ OTHER ____

AVIONICS ____ PROPULSION ____ VEHICLE SUPPORT ____ FACILITIES ____ PAYLOAD ____ SYS SAFETY X

ACTION RECOMMENDED:

Stabilization controls should have back-up capability to provide OPD stabilization in case the primary controls fail. No docking attempt should be made between unstable vehicles. Docking should be locally and automatically controlled. Redundant release mechanisms should be incorporated.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				CRITICAL

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED

OPERATIONAL
HAZARD ANALYSIS

PAGE 1 OF 1
DATE
REV

END ITEM Tug/Propellant Module/OPD

SUBSYSTEM Structural

SUBSYSTEM IDENT NO. 5

OPERATION/PHASE
Orbital - Dock Propellant Module To OPD

OP. IDENT. NO. C

HAZARD GROUP
Reduced Integrity Of Structure Or Equipment

HAZARD GRP. CODE 2

REFERENCES
FMEA 4.3A

AUTHORITY Task II-3

HAZARD DESCRIPTION/ EFFECTS Misalignment between the axis of the OPD and propellant module docking ports greater than 7° angle could create a hazard. The hazard is potential damage of the interconnect fixture which could structurally damage the electrical line interconnects, or propellant and pressurization line connections.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			CRITICAL

COPIES TO: STRUCTURAL ___ MECHANICAL ___ MATERIALS ___ GSE ___ OTHER ___

AVIONICS ___ PROPULSION ___ VEHICLE SUPPORT ___ FACILITIES ___ PAYLOAD ___ SYS SAFETY X

ACTION RECOMMENDED:

The final closing attitude of the docking maneuver should be automatically controlled (with manual override) to limit the angular deviation to design tolerance.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				MARGINAL

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED ______

OPERATIONAL
HAZARD ANALYSIS

DATE ______

REV ______

END ITEM Tug/Propellant Module/OPD	SUBSYSTEM Structural	SUBSYSTEM IDENT NO. 5
OPERATION/PHASE Orbital - Undock From Module		OP. IDENT. NO. C
HAZARD GROUP Disturbances		HAZARD GRP. CODE 12
REFERENCES FMEA 4.4A		AUTHORITY Project II, Task II-3

HAZARD DESCRIPTION/ EFFECTS Failure of one of the docking ring capture latches to release the Tug docking ring could establish the condition for a disturbance hazard. This hazard could be initiated by action of the RCS to separate. The hangup would thus impart a rotational movement into the OPD which in turn would cause the propellant to slosh. The slosh coupled with the dynamics of the configuration could produce conditions leading to possible structural failure.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			CATASTROPHIC

COPIES TO: STRUCTURAL ____ MECHANICAL ____ MATERIALS ____ GSE ____ OTHER ____

AVIONICS ____ PROPULSION ____ VEHICLE SUPPORT ____ FACILITIES ____ PAYLOAD ____ SYS SAFETY X

ACTION RECOMMENDED:

The control operator should have verification of capture latch disengagement. Procedure controls should be implemented to prohibit separation until capture latches are disengaged. Redundant release mechanisms should be incorporated.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				MARGINAL

109

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED ______

OPERATIONAL HAZARD ANALYSIS

PAGE 1 OF 1

DATE ______

REV ______

END ITEM Tug/OPD	SUBSYSTEM Avionics	SUBSYSTEM IDENT NO. 1
OPERATION/PHASE Orbital - Manuever To User Port And Dock		OP. IDENT. NO. C
HAZARD GROUP Impact		HAZARD GRP. CODE 8
REFERENCES FMEA 4.5A		AUTHORITY Project II, Task II-3

HAZARD DESCRIPTION/ EFFECTS An impact hazard can occur in executing the maneuver from the propellant module to docking at the user port of the OPD. This can occur if the RCS responds intermittently to the control requirement, from failure of the proper thrusters to ignite. Failure of the control system (Avionics) or inhibiting the thruster operation in the wrong direction could also create the hazard. Under this condition the Tug could reasonably be expected to go into a rotational maneuver which could impact the OPD or docked vehicles. The hazard is amplified if consideration of the best traffic pattern to use is not preplanned and movement is attempted into a high density traffic area.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			CRITICAL

COPIES TO: STRUCTURAL ____ MECHANICAL ____ MATERIALS ____ GSE ____ OTHER ____

AVIONICS ____ PROPULSION ____ VEHICLE SUPPORT ____ FACILITIES ____ PAYLOAD ____ SYS SAFETY X

ACTION RECOMMENDED:

Secondary thruster controls should be incorporated to provide rotational control during docking maneuvers in case the primary controls fail.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				MARGINAL

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED ____

OPERATIONAL HAZARD ANALYSIS

DATE ____

REV ____

END ITEM Tug/OPD	SUBSYSTEM Avionics	SUBSYSTEM IDENT NO. I
OPERATION/PHASE Orbital - Maneuver To User Port And Dock		OP. IDENT. NO. C
HAZARD GROUP *Loss Of Communications*		HAZARD GRP. CODE 11
REFERENCES FMEA 4.5A FMEA 4.9A		AUTHORITY Task II-3

HAZARD DESCRIPTION/ EFFECTS It is expected that during the operation of the Tug the TV aids provided for ground intelligence during maneuvering and docking will fail. This failure may be electronics failure or sensor burning due to orientation into the sun. It could be postulated that these failures could occur during the maneuvering process and at the time of occurrence could leave ground control or Shuttle operations in a situation where the system would be vulnerable to impact damage if the TV from the OPD could not pick up the Tug location.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			CRITICAL

COPIES TO: STRUCTURAL ____ MECHANICAL ____ MATERIALS ____ GSE ____ OTHER ____

AVIONICS ____ PROPULSION ____ VEHICLE SUPPORT ____ FACILITIES ____ PAYLOAD ____ SYS SAFETY X

ACTION RECOMMENDED:

Critical docking aids should have alternate or back-up systems to be used if the primary systems fail. Back-out procedures should be implemented to safely terminate the operations in progress in case the secondary capability fails.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				MARGINAL

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED ______

OPERATIONAL
HAZARD ANALYSIS

PAGE 1 OF 1
DATE ______
REV ______

END ITEM Tug/OPD	SUBSYSTEM Structural - Docking Ring	SUBSYSTEM IDENT NO. 5
OPERATION/PHASE Orbital - Maneuver To User Port And Dock		OP. IDENT. NO. C
HAZARD GROUP Impact		HAZARD GRP. CODE 8
REFERENCES FMEA 4.5A FMEA 4.9A		AUTHORITY TASK II-3

HAZARD DESCRIPTION/ EFFECTS During the docking approach, incorrect alignment of the docking ring axis greater than seven degrees could prevent capture and depending on the extent of misalignment could impact the docking ring with the line interconnect fixture face causing damage which could preclude follow on transfer of propellants into the Tug. If the damage to the interface connector system is not known and line hookup is initiated after docking, the Tug/OPD could be subjected to cryogenic fluid ice crystals and pressure venting through the gas pressurization line.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			CRITICAL

COPIES TO: STRUCTURAL ____ MECHANICAL ____ MATERIALS ____ GSE ____ OTHER ____

AVIONICS ____ PROPULSION ____ VEHICLE SUPPORT ____ FACILITIES ____ PAYLOAD ____ SYS SAFETY X

ACTION RECOMMENDED:

The final closing attitude of the docking maneuver should be automatically controlled (with manual over-ride) to limit the angular deviation to design tolerance. A means should be provided to verify that interface connectors have been mated and are leak-tight prior to initiating fluid flow.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				MARGINAL

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED

OPERATIONAL
HAZARD ANALYSIS

PAGE 1 OF 1
DATE
REV

END ITEM Tug/OPD	SUBSYSTEM Avionoics	SUBSYSTEM IDENT NO. 1
OPERATION/PHASE Orbital - Maneuver To User Port And Dock		OP. IDENT. NO. C
HAZARD GROUP Loss Of Communication		HAZARD GRP. CODE 11
REFERENCES FMEA 4.5A FMEA 4.9A		AUTHORITY Project II, Task II-3

HAZARD DESCRIPTION/ EFFECTS Failure of the intelligence module to communicate data to the control crew (ground, space shuttle, space station) or alternatively failure of the control crew to communicate during the maneuvering operation to dock imposes a hazard - loss of control of the mission operation. This loss of remote control capability will result in a case with varying degrees of hazard. In the event the onset of the failure occurs at an operation of a critical function, the results could be catastrophic (failure to command thrusters off) leading to OPD destruction. The other extreme would be translation away from the OPD with no hazard.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			CATASTROPHIC

COPIES TO: STRUCTURAL ___ MECHANICAL ___ MATERIALS ___ GSE ___ OTHER ___

AVIONICS ___ PROPULSION ___ VEHICLE SUPPORT ___ FACILITIES ___ PAYLOAD ___ SYS SAFETY X

ACTION RECOMMENDED:

Alternate communications links should be provided that automatically switch in should the primary link fail.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				MARGINAL

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED ______

OPERATIONAL HAZARD ANALYSIS

DATE ______

REV ______

END ITEM Tug/OPD/ Propellant Module	SUBSYSTEM Propellant	SUBSYSTEM IDENT NO. 11
OPERATION/PHASE Orbital - Transfer/Unload Propellant Module To OPD OPD To Tug		OP. IDENT. NO. C
HAZARD GROUP Reduced Integrity Of Structure Or Equipment		HAZARD GRP. CODE 2
REFERENCES FMEA 4.6A FMEA 4.7A		AUTHORITY TASK II-3

HAZARD DESCRIPTION/EFFECTS The docking operation if completed without removal of the line interconnect fixture meteoroid shield could create a hazard causing damage to the indexing probes. Without retraction of the shield, the operation for indexing and rigidizing the fixture for line attachment would drive the indexing probe through the shield causing loss of capability to rigidize the interface. The damage may also cause the index probe chain drive to break, rendering the system inoperative.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			CRITICAL

COPIES TO: STRUCTURAL ____ MECHANICAL ____ MATERIALS ____ GSE ____ OTHER ____

AVIONICS ____ PROPULSION ____ VEHICLE SUPPORT ____ FACILITIES ____ PAYLOAD ____ SYS SAFETY X

ACTION RECOMMENDED:

The control crewman should be provided with positive verification of the retraction of the line interconnect shield. Procedural controls should be implemented to prohibit final docking with shield not retracted.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				MARGINAL

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED

OPERATIONAL HAZARD ANALYSIS

DATE

REV

END ITEM Tug/OPD Propellant Module	SUBSYSTEM Propellant	SUBSYSTEM IDENT NO. 11
OPERATION/PHASE Orbital - Transfer/Unload Propellant Module To OPD OPD To Tug		OP. IDENT. NO. C
HAZARD GROUP Fire/Explosion, Heat/Temperature		HAZARD GRP. CODE 1, 6
REFERENCES FMEA 4.6A FMEA 4.7A		AUTHORITY TASK II-3

HAZARD DESCRIPTION/ EFFECTS

Mechanical failure of the line extension bellows in the line interconnect fixture would produce a potential fire or explosion if the fixture is not open to ambient pressure. A mass spill by rupture will create a hazard in the docking area caused by ice crystal formation over the structure, TV lens, view ports, and in the surrounding area.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			CATASTROPHIC

COPIES TO: STRUCTURAL ____ MECHANICAL ____ MATERIALS ____ GSE ____ OTHER ____

AVIONICS ____ PROPULSION ____ VEHICLE SUPPORT ____ FACILITIES ____ PAYLOAD ____ SYS SAFETY X

ACTION RECOMMENDED:

Propellant handling lines and bellows should be exposed to space vacuum and not confined to minimize the fire/explosion hazard. Retractible shields should be provided to shield visual aids against clouds of "ice" crystals created by propellant leaks.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				CRITICAL

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED ______

OPERATIONAL HAZARD ANALYSIS

PAGE 1 OF 1
DATE ______
REV ______

END ITEM Tug/OPD/ Propellant Module	SUBSYSTEM Propellant	SUBSYSTEM IDENT NO. 11
OPERATION/PHASE Orbital - Transfer/Unload Propellant	Module To OPD OPD To Tug	OP. IDENT. NO. C
HAZARD GROUP Fire/Explosion		HAZARD GRP. CODE 1
REFERENCES FMEA 4.6A FMEA 4.7A		AUTHORITY TASK II-3

HAZARD DESCRIPTION/EFFECTS Fluid leakage from the line interconnect fixture quick disconnects could create an explosive or fire hazard where the leakage was contained in a confined area or compartment. This problem is not a hazard if the leakage is vented to ambient pressure. The cause of the leakage would probably be contamination, or a defective seal. Both LO2 and LH_2 must leak and mix for fire to occur. This could occur where both LO2 and LH2 lines are run through the same line interconnect fixture.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			CRITICAL

COPIES TO: STRUCTURAL ___ MECHANICAL ___ MATERIALS ___ GSE ___ OTHER ___

AVIONICS ___ PROPULSION ___ VEHICLE SUPPORT ___ FACILITIES ___ PAYLOAD ___ SYS SAFETY X

ACTION RECOMMENDED:

The components of the propellant transfer system that could leak through wear, contamination or failure should not be located in a confined area to minimize the hazard of fire/explosion. Interface leak checks should be made prior to initiating propellant flow.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				MARGINAL

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED ______

INTEGRATION
HAZARD ANALYSIS

PAGE 1 OF 1
DATE ______
REV ______

END ITEM Tug/OPD/Propellant Module/Equipment Module — SUBSYSTEM Pressurization	SUBSYSTEM IDENT NO. 13
OPERATION/PHASE Orbital - Transfer/Unload Propellant — Module To OPD, OPD To Tug	OP. IDENT. NO. C
HAZARD GROUP Reduced Integrity Of Structure Or Equipment	HAZARD GRP. CODE 2
REFERENCES FMEA 4.6A FMEA 4.7A	AUTHORITY Project II, Task II-3

HAZARD DESCRIPTION/ EFFECTS The gas generator fuel supply pump provides fuel to the combustor under an NPSH from an initial NPSH of zero. In the bootstrap operation, cavitation due to erratic fuel flow to the pump could restrict the output head below the point where the heat exchanger could operate in a stable condition. This condition could generate oscillations within the heat exchanger causing damage internally or reduce the heat exchanger integrity. This gas generator is required by user or receiver vehicles during OPD operations.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			CRITICAL

COPIES TO: STRUCTURAL ___ MECHANICAL ___ MATERIALS ___ GSE ___ OTHER ___

AVIONICS ___ PROPULSION ___ VEHICLE SUPPORT ___ FACILITIES ___ PAYLOAD ___ SYS SAFETY X

ACTION RECOMMENDED:

Provide accumulators that will insure the availability of liquid propellants to the gas generator under all conditions of operation. Proof test heat exchanger to insure that it will operate under credible conditions of oscillating pressure.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				MARGINAL

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED

INTEGRATION
HAZARD ANALYSIS

PAGE 1 OF 1
DATE
REV

END ITEM Tug/OPD/Propellant Module/Equip. Mod.	SUBSYSTEM Pressurization	SUBSYSTEM IDENT NO. 13
OPERATION/PHASE Orbital - Transfer/Unload Propellant Module To OPD, OPD To PPS-7		OP. IDENT. NO. C
HAZARD GROUP Fire/Explosion, Contamination		HAZARD GRP. CODE 1, 3
REFERENCES FMEA 4.6A FMEA 4.7A		AUTHORITY Project II, Task II-3

HAZARD DESCRIPTION/ EFFECTS Hot gas from the gas generator to the heat exchanger could exceed the design limit temperature, should a control failure occur. A hazard is thus created resulting in possible burn-through of the heat exchanger, resulting in fire in the equipment module. Should the heat exchanger burn-through occur in the exchanger walls, the equipment module will be filled with products of combustion. The magnitude of the destructive effects of this type of hazard are dependent on reaction time of the control operator/or safety devices.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			CRITICAL

COPIES TO: STRUCTURAL ___ MECHANICAL ___ MATERIALS ___ GSE ___ OTHER ___

AVIONICS ___ PROPULSION ___ VEHICLE SUPPORT ___ FACILITIES ___ PAYLOAD ___ SYS SAFETY X

ACTION RECOMMENDED:

Protective devices should be incorporated in the gas generator outlet that would sense hot gas temperature and pressure and automatically terminate propellant flow to the gas generator if these parameters exceed the design limits.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				MARGINAL

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED

OPERATIONAL
HAZARD ANALYSIS

DATE

REV

END ITEM Tug/OPD/Propellant Module/Equip. Module	SUBSYSTEM Propellant	SUBSYSTEM IDENT NO. 11
OPERATION/PHASE Orbital - Transfer/Unload Propellants Module To OPD OPD To Tug		OP. IDENT. NO. C
HAZARD GROUP Disturbances		HAZARD GRP. CODE 12
REFERENCES FMEA 4.6A FMEA 4.7A		AUTHORITY Project II, Task II-3

HAZARD DESCRIPTION/ EFFECTS Hazards are created by vehicle and propellant dynamic interaction which can cause (1) uncovering of the source tank outlet, (2) venting of liquid from the receiver tank, (3) structural failure and (4) gas entrapment within the receiver tank capillary compartments. The vehicle and propellant dynamic interaction are caused by (a) CG changes due to fluid transfer from tank to tank and (b) propellant CG excursion (sloshing) within each tank. The effects of this hazard lead to instability (disturbances) possible pump cavitation, slug flow between tanks and possible structural failure with loss of mission equipment module crew.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			CATASTROPHIC

COPIES TO: STRUCTURAL ___ MECHANICAL ___ MATERIALS ___ GSE ___ OTHER ___

AVIONICS ___ PROPULSION ___ VEHICLE SUPPORT ___ FACILITIES ___ PAYLOAD ___ SYS SAFETY X

ACTION RECOMMENDED:

Provide vortex, slosh baffles and liquid/vapor separators to minimize the possibility of two phase flow during propellant transfer. A means should be provided to verify that propellants had settled and procedural controls implemented to prohibit transfer prior to propellant settling.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				CRITICAL

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED ______

OPERATIONAL
HAZARD ANALYSIS

DATE ______

REV ______

END ITEM Tug/OPD/ Propellant Module	SUBSYSTEM Propellant	SUBSYSTEM IDENT NO. 11
OPERATION/PHASE Orbital - Transfer/Unload Propellents	Module To OPD OPD To Tug	OP. IDENT. NO. C
HAZARD GROUP Disturbances		HAZARD GRP. CODE 12
REFERENCES FMEA 4.6A FMEA 4.7A		AUTHORITY Project II, Task II-3

HAZARD DESCRIPTION/ EFFECTS A potential hazard is created during propellant transfer operations in near zero "G" associated with receiver tank inlet fluid momentum. There is a possibility of severe distortion of the liquid surface due to the flow energy, which can cause disturbances in the vehicle, capable of becoming destructive. As propellant inlet momentum increases, resulting surface disturbances will also increase. The effect of this hazard can lead to severe instability, structural failure and loss of mission, through excursion of the configuration CG.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			CATASTROPHIC

COPIES TO: STRUCTURAL ___ MECHANICAL ___ MATERIALS ___ GSE ___ OTHER ___

AVIONICS ___ PROPULSION ___ VEHICLE SUPPORT ___ FACILITIES ___ PAYLOAD ___ SYS SAFETY X

ACTION RECOMMENDED:

Provide slosh baffles to minimize distortion of free liquid surface. A study should be conducted to verify that the dynamic stability of the coupled vehicles will not be jeopardized by fluid transfer momentum.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				CRITICAL

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED

OPERATIONAL
HAZARD ANALYSIS

DATE

REV

END ITEM Tug/OPD/ Propellant Module	SUBSYSTEM Propulsion	SUBSYSTEM IDENT NO. 2
OPERATION/PHASE Orbital - Transfer/Unload Propellants Module To OPD OPD To Tug		OP. IDENT. NO. C
HAZARD GROUP Loss Of Attitude Control, Disturbances		HAZARD GRP. CODE 9, 12
REFERENCES FMEA 4.6A FMEA 4.7A		AUTHORITY Project II, Task II-3

HAZARD DESCRIPTION/ EFFECTS The spin up operation using the reaction control system could create hazards associated with "G" loads and disturbances due to sloshing. The hazard can be caused by application of thrust to the OPD which in turn initiates the condition for sloshing. Any intermittent firing from the RCS could amplify the sloshing which through coupling with the OPD could be destructive. The conditions for intermittent firing could be set by uncovering of the propellant inlet in the source tanks due to severe distortion of the liquid surface. Any uneveness in spin rate or side motion can cause the undesirable propellant motion.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			CATASTROPHIC

COPIES TO: STRUCTURAL ____ MECHANICAL ____ MATERIALS ____ GSE ____ OTHER ____

AVIONICS ____ PROPULSION ____ VEHICLE SUPPORT ____ FACILITIES ____ PAYLOAD ____ SYS SAFETY X

ACTION RECOMMENDED:

Slosh dampening devices should be incorporated that will limit liquid excursions to safe levels. RCS controls should have back-up capability to insure continued operation. Accumulators should be incorporated to insure continuous availability of propellants to RCS.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				CRITICAL

121

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED ______

OPERATIONAL
HAZARD ANALYSIS

DATE ______

REV ______

END ITEM Tug/OPD/ Propellant Module	SUBSYSTEM Propellant	SUBSYSTEM IDENT NO. 11
OPERATION/PHASE Orbital - Transfer/Unload Propellant Module To OPD OPD To PRS-7		OP. IDENT. NO. C
HAZARD GROUP Reduced Integrity Of Structure Or Equipment		HAZARD GRP. CODE 2
REFERENCES FMEA 4.6A FMEA 4.7A		AUTHORITY Project II, Task II-3

HAZARD DESCRIPTION/ EFFECTS Lack of a zero "G" propellant gaging system in the OPD baseline places increased importance on the system flowmeters. Failure of a flowmeter creates hazards in the following manner. Loss of accurate transfer data through electro/mechanical failure or two phase flow caused by disturbances, cause loss of data on CG location, requiring extrapolation from last known condition. The lack of accurate data thus aggravates the disturbance factor and CG control. The extreme hazard could result in loss of mission through structural failure due to vehicle and propellant dynamics interaction.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			CRITICAL

COPIES TO: STRUCTURAL ____ MECHANICAL ____ MATERIALS ____ GSE ____ OTHER ____

AVIONICS ____ PROPULSION ____ VEHICLE SUPPORT ____ FACILITIES ____ PAYLOAD ____ SYS SAFETY X

ACTION RECOMMENDED:

A propellant measuring device that will accurately measure propellant quantities remaining should be incorporated in the OPD tanks. Propellant level should be measured by conventional methods, after propellant settling, if a Zero G method is not available.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				MARGINAL

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED

OPERATIONAL

HAZARD ANALYSIS

PAGE 1 OF 1

DATE

REV

END ITEM OPD/Equipment Module	SUBSYSTEM Pressurization	SUBSYSTEM IDENT NO. 13
OPERATION/PHASE Orbital - Transfer/Unload Propellant	Module To OPD OPD To Tug	OP. IDENT. NO. C
HAZARD GROUP Heat/Temperature		HAZARD GRP. CODE 6
REFERENCES FMEA 4.6A FMEA 4.7A		AUTHORITY Project II, Task II-3

HAZARD DESCRIPTION/ EFFECTS Failure of the LO_2 regulator, to the gas generator, in the open mode will allow an oxygen rich condition to occur within the gas generator which if undetected or not shutdown will cause excessive temperatures within the GG and heat exchanger. This condition could reasonably be expected to cause burn-through of the CG and heat exchanger located in the equipment module. The extent of this hazard is dependent on related action response time of the personnel controlling operations or the automatic safety devices.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			CRITICAL

COPIES TO: STRUCTURAL ____ MECHANICAL ____ MATERIALS ____ GSE ____ OTHER ____

AVIONICS ____ PROPULSION ____ VEHICLE SUPPORT ____ FACILITIES ____ PAYLOAD ____ SYS SAFETY X

ACTION RECOMMENDED:

Protective devices should be incorporated in the GG outlet that would sense hot gas temperature and pressure and automatically terminate propellant flow to the GG if these parameters exceed the design limit.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				MARGINAL

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED ______

OPERATIONAL

HAZARD ANALYSIS

PAGE 1 OF 1

DATE ______

REV ______

END ITEM Tug/OPD	SUBSYSTEM Mechanical	SUBSYSTEM IDENT NO. 4
OPERATION/PHASE Orbital - Undock		OP. IDENT. NO. C
HAZARD GROUP Reduced Integrity Of Structure Or Equipment		HAZARD GRP. CODE 2
REFERENCES FMEA 4.8A FMEA 4.9A		AUTHORITY TASK II-3

HAZARD DESCRIPTION/ EFFECTS The indexing probes at the corners of the line interconnect fixture on the OPD are used to rigidize the interface for line hookup. A hazard could be created to the Tug/OPD if the indexing probes are prematurely withdrawn from the interface. Movement in this case would cause damage to the line probes and if the action is one that sets up an oscillating movement, it could damage the interface of the interconnect lines by crushing.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			CRITICAL

COPIES TO: STRUCTURAL ____ MECHANICAL ____ MATERIALS ____ GSE ____ OTHER ____

AVIONICS ____ PROPULSION ____ VEHICLE SUPPORT ____ FACILITIES ____ PAYLOAD ____ SYS SAFETY X

ACTION RECOMMENDED:

A positive verification of indexing probe release should be provided to the control operator. Procedural controls and training should be implemented to prohibit the application of propulsive energy prior to release.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				MARGINAL

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED

OPERATIONAL HAZARD ANALYSIS

DATE

REV

END ITEM Tug/OPD/ Propellant Module	SUBSYSTEM Mechanical	SUBSYSTEM IDENT NO. 4
OPERATION/PHASE Orbital - Undock		OP. IDENT. NO. C
HAZARD GROUP Loss Of Attitude Control, Implosion/Explosion		HAZARD GRP. CODE 9, 1
REFERENCES FMEA 4.8A FMEA 4.9A		AUTHORITY TASK II-3

HAZARD DESCRIPTION/ EFFECTS At the time of pressurization line QD separation at the line interconnect fixture, failure of the OPD pressurization line QD to seat (fail open) could provide a propulsive venting condition which upon complete separation of the Tug or propellant module, could impart linear or rotational acceleration to the OPD. The same is true if the QD fails open on the Tug/propellant module interface side. An acceleration could be imparted to the Tug/propellant module. If this condition were not noted (minor leakage) and the leakage occurred in the Shuttle cargo bay, the down module may implode/explode upon deorbit into the earth's atmosphere.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			CRITICAL

COPIES TO: STRUCTURAL ____ MECHANICAL ____ MATERIALS ____ GSE ____ OTHER ____

AVIONICS ____ PROPULSION ____ VEHICLE SUPPORT ____ FACILITIES ____ PAYLOAD ____ SYS SAFETY X

ACTION RECOMMENDED:

The attitude control system should be sized to counteract credible leaks. Consideration should be given to configuring the QD such that large volume leakage would be non-propulsive. Leak checks should be performed prior to emplacement in the cargo bay.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				MARGINAL

125

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED

OPERATIONAL
HAZARD ANALYSIS

DATE
REV

END ITEM Tug/OPD	SUBSYSTEM Mechanical	SUBSYSTEM IDENT NO. 4
OPERATION/PHASE Orbital - Undock		OP. IDENT. NO. C
HAZARD GROUP Reduced integrity of structure or equipment, disturbance		HAZARD GRP. CODE 2, 12
REFERENCES FMEA 4.8A FMEA 4.9A		AUTHORITY TASK II-3

HAZARD DESCRIPTION/EFFECTS Failure of one of the docking ring latches to unlatch creates a potential hazard to the Tug/OPD. This could be caused as a result of the electro/mechanical system to properly function. With remote control, if the failure is not detected, the RCS could be activated causing the Tug/OPD configuration to rotate. Disturbance of the fluid and CG location could create a dynamic coupling of the configuration which is undesirable, and may ultimately lead to system structural damage. The same situation is created where a docking ring latch hangs up due to separation misalignment.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			CATASTROPHIC

COPIES TO: STRUCTURAL ____ MECHANICAL ____ MATERIALS ____ GSE ____ OTHER ____

AVIONICS ____ PROPULSION ____ VEHICLE SUPPORT ____ FACILITIES ____ PAYLOAD ____ SYS SAFETY X

ACTION RECOMMENDED:

A positive verification of docking latch release should be provided to the control operator. Procedural controls and training should be implemented to prohibit the application of propulsive energy prior to release. Redundant release mechanisms should be incorporated to be used in case the primary mode fails.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				CRITICAL

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED

OPERATIONAL
HAZARD ANALYSIS

DATE

REV

END ITEM Tug/OPD/ Propellant Module	SUBSYSTEM Avionics	SUBSYSTEM IDENT NO. 1
OPERATION/PHASE Orbital - Undock		OP. IDENT. NO. C
HAZARD GROUP Reduced Integrity Of Structure Or Equipment		HAZARD GRP. CODE 2
REFERENCES FMEA 4.8A FMEA 4.9A		AUTHORITY TASK II-3

HAZARD DESCRIPTION/ EFFECTS Failure to withdraw the electrical lines in the interconnect fixture, either because of operational procedures or mechanical failure, before undocking introduces the potential hazard of damage to the OPD side of the interface, which through the bending or failure of the pins could render the interface destroyed for future use. This damage could cause direct shorts, welding of contacts or open circuits for the next vehicle docking at the OPD interface.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			CRITICAL

COPIES TO: STRUCTURAL ___ MECHANICAL ___ MATERIALS ___ GSE ___ OTHER ___

AVIONICS ___ PROPULSION ___ VEHICLE SUPPORT ___ FACILITIES ___ PAYLOAD ___ SYS SAFETY X

ACTION RECOMMENDED:

The control operator should be provided with verification of withdrawal of the electrical lines. Training and procedural controls should be implemented to prohibit undocking prior to unhooking. Back-up means should be incorporated to separate electrical connectors in case of the failure of the primary means.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				MARGINAL

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED ______

OPERATIONAL
HAZARD ANALYSIS

PAGE 1 OF 1
DATE ______
REV ______

END ITEM Tug/Orbiter/ Centaur D1-T	SUBSYSTEM Propulsion	SUBSYSTEM IDENT NO. 2
OPERATION/PHASE Orbital/Deorbit - Rendezvous With Orbiter		OP. IDENT. NO. C, D
HAZARD GROUP Impact		HAZARD GRP. CODE 8
REFERENCES FMEA 4.11A		AUTHORITY TASK II-3

HAZARD DESCRIPTION/ EFFECTS

Failure of the Auxiliary Propulsion System (APS) during the terminal phase finalization braking operation could cause orbit intercept to occur, causing impact between the Orbiter and Tug/payload down module or Centaur. This could occur through failure of the APS controls or failure to respond to proper control signals.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			CRITICAL

COPIES TO: STRUCTURAL ____ MECHANICAL ____ MATERIALS ____ GSE ____ OTHER ____

AVIONICS ____ PROPULSION ____ VEHICLE SUPPORT ____ FACILITIES ____ PAYLOAD ____ SYS SAFETY X

ACTION RECOMMENDED:

The APS controls system should be provided with alternate or back-up systems that would automatically become functional if the primary system fails.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				Marginal

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED

OPERATIONAL HAZARD ANALYSIS

PAGE 1 OF 1

DATE

REV

END ITEM Tug/Down Module/ Centaur D1-T	SUBSYSTEM Avionics/Propulsion	SUBSYSTEM IDENT NO. 1, 2
OPERATION/PHASE Orbital - Rendezvous With Orbiter Deorbit		OP. IDENT. NO. C, D
HAZARD GROUP Loss Of Attitude Control		HAZARD GRP. CODE 9
REFERENCES FMEA 4.11A		AUTHORITY TASK II-3

HAZARD DESCRIPTION/ EFFECTS Control failure or failure of the attitude control motors to either fire or fire intermittently, could render the vehicle unstable and incapable of attitude hold control to allow the Orbiter to recover the down module. An additional potential hazard could be created if the operational decision were made by the Orbiter crew to attempt hookup in the unstable mode. This could lead to potential impact conditions.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			CRITICAL

COPIES TO: STRUCTURAL ____ MECHANICAL ____ MATERIALS ____ GSE ____ OTHER ____

AVIONICS ____ PROPULSION ____ VEHICLE SUPPORT ____ FACILITIES ____ PAYLOAD ____ SYS SAFETY X

ACTION RECOMMENDED:

The controls of the ACS should be provided with secondary capability to automatically provide attitude control in case of failure of the primary system. Procedural controls should be implemented to prohibit attempts to dock with an unstable module.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				MARGINAL

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED ______

OPERATIONAL
HAZARD ANALYSIS

DATE ______
REV ______

END ITEM Tug/Down Module Centaur/Orbiter	SUBSYSTEM Avionics-Propulsion	SUBSYSTEM IDENT NO. 1, 2
OPERATION/PHASE Orbital/Deorbit - Rendezvous with Orbiter		OP. IDENT. NO. C
HAZARD GROUP Impact		HAZARD GRP. CODE 8
REFERENCES FMEA 4.11A		AUTHORITY TASK II-3

HAZARD DESCRIPTION/ EFFECTS In executing closure burn, tug/centaur could impact the orbiter if the closure burn is excessive in time and the braking action is not effective or not considered necessary. This could occur as a potential hazard where coordination between orbiter control and ground control is not finite and/or through control or data failure, to the control group. Impact could be expected in the form of the vehicle moving the down module into the orbiter structure.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			CRITICAL

COPIES TO: STRUCTURAL ___ MECHANICAL ___ MATERIALS ___ GSE ___ OTHER ___

AVIONICS ___ PROPULSION ___ VEHICLE SUPPORT ___ FACILITIES ___ PAYLOAD ___ SYS SAFETY X

ACTION RECOMMENDED:

The final closing velocity/attitude of the docking maneuver should be automatically controlled (with manual override) to limit the approach velocity/attitude of the mating vehicles to design tolerances. The data transmission to achieve automatic control should be between docking vehicles and not through a ground link. Communications circuits should have backup capability.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				MARGINAL

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED ______

OPERATIONAL HAZARD ANALYSIS

PAGE 1 OF 1
DATE ______
REV ______

END ITEM Tug	SUBSYSTEM Avionics/Propulsion	SUBSYSTEM IDENT NO. 1/2
OPERATION/PHASE Orbital/Stand off from shuttle orbiter		OP. IDENT. NO. C
HAZARD GROUP Loss of attitude control		HAZARD GRP. CODE 9
REFERENCES FMEA 4.12A		AUTHORITY TASK II-3

HAZARD DESCRIPTION/ EFFECTS

During the stand off period in orbits of 100 nm, any failure of the tug to be able to start the attitude control system, would leave the tug in a condition where the orbit will degrade causing the tug to make an uncontrolled earth re-entry. Loss of orbital maintenance capability will thus cause loss of mission.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			CATASTROPHIC

COPIES TO: STRUCTURAL ____ MECHANICAL ____ MATERIALS ____ GSE ____ OTHER ____

AVIONICS ____ PROPULSION ____ VEHICLE SUPPORT ____ FACILITIES ____ PAYLOAD ____ SYS SAFETY X

ACTION RECOMMENDED:

The attitude control start system should be provided with multiple capability to insure the ability to maintain attitude during critical phase of the operation.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				CRITICAL

131

CONTRACT NAS 8-27692

LOCATION/SITE INVOLVED ______

OPERATIONAL
HAZARD ANALYSIS

PAGE 1 OF 1
DATE ______
REV ______

END ITEM Tug/Down Module/Orbiter	SUBSYSTEM Propulsion	SUBSYSTEM IDENT NO. 2
OPERATION/PHASE Orbital - Stand off from shuttle orbiter		OP. IDENT. NO. C
HAZARD GROUP Loss of attitude control, Impact		HAZARD GRP. CODE 9, 8
REFERENCES FMEA 4.12A		AUTHORITY TASK II-3

HAZARD DESCRIPTION/ EFFECTS

In translating away from the orbiter to a stand-off position, erroneous control signals, human error or intermittent RCS operation of opposing sets of engines could be expected to produce pitch or yaw conditions which may result in impact with the orbiter manipulators, or drive the tug into the orbiter. These erroneous signals could be the result of transfer of control responsibility, human error or system failure.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			CATASTROPHIC

COPIES TO: STRUCTURAL ___ MECHANICAL ___ MATERIALS ___ GSE ___ OTHER ___

AVIONICS ___ PROPULSION ___ VEHICLE SUPPORT ___ FACILITIES ___ PAYLOAD ___ SYS SAFETY X

ACTION RECOMMENDED:

RCS controls should be provided with backup capability that automatically (with manual override) provides attitude control should the primary mode fail. The operating crew should be trained and guided by procedural controls to minimize human error. Emphasis should be placed on correct transfer of responsibility.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				CRITICAL

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED

HAZARD ANALYSIS

DATE

REV

END ITEM Shuttle Booster/ESS	SUBSYSTEM Propellant	SUBSYSTEM IDENT NO. 11
OPERATION/PHASE Prelaunch		OP. IDENT. NO. A
HAZARD GROUP Fire/Explosion/Implosion		HAZARD GRP. CODE 1
REFERENCES FMEA 2.3B		AUTHORITY Project II, Task 3

HAZARD DESCRIPTION/ EFFECTS

Excessive fill rate during childown of the LH_2 tank could cause the J-weld area to overstress causing structural failure. This could be expected to cause a fire/explosion with loss of the stage.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			CATASTROPHIC

COPIES TO: STRUCTURAL ___ MECHANICAL ___ MATERIALS ___ GSE ___ OTHER ___

AVIONICS ___ PROPULSION ___ VEHICLE SUPPORT ___ FACILITIES ___ PAYLOAD ___ SYS SAFETY X

ACTION RECOMMENDED:

Procedural controls should be implemented to limit the flow rate on childown to prohibit thermal overstress. Consideration should be given to employing an automatic loading cycle (with manual over-ride).

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				MARGINAL

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED ______

HAZARD ANALYSIS

PAGE 1 OF 1

DATE ______

REV ______

END ITEM ESS	SUBSYSTEM Pressurization	SUBSYSTEM IDENT NO. 13
OPERATION/PHASE Prelaunch, Launch/Ascent		OP. IDENT. NO. A, B
HAZARD GROUP Fire/Explosion/Implosion		HAZARD GRP. CODE 1
REFERENCES FMEA 2.3B		AUTHORITY

HAZARD DESCRIPTION/ EFFECTS

Failure of the LO2 vent valve in an "open" mode after LH_2 tank pressurization could result in common bulkhead collapse leading to loss of vehicle and mission. Fire and explosion could be expected.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			CATASTROPHIC

COPIES TO: STRUCTURAL ___ MECHANICAL ___ MATERIALS ___ GSE ___ OTHER ___

AVIONICS ___ PROPULSION ___ VEHICLE SUPPORT ___ FACILITIES ___ PAYLOAD ___ SYS SAFETY X

ACTION RECOMMENDED:

Automatic corrective action should be incorporated to vent the LH2 tank when the LO2 tank pressure falls below the pressure in the LH2 tank to insure the design delta across the common bulkhead is not exceeded. Launch abort and emergency propellant off-load would result.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				CRITICAL

CONTRACT ______

LOCATION/SITE INVOLVED ______

HAZARD ANALYSIS

PAGE ____ OF ____
DATE ______
REV ______

END ITEM ESS	SUBSYSTEM Propellant	SUBSYSTEM IDENT NO. 11
OPERATION/PHASE Prelaunch, Launch/Ascent		OP. IDENT. NO. A, B
HAZARD GROUP Loss Of Thrust		HAZARD GRP. CODE 7
REFERENCES FMEA 2.3B		AUTHORITY

HAZARD DESCRIPTION/ EFFECTS

Loss of helium gas injection into the LO2 recirculation system due to the failure of the He regulator, in a closed condition, would cause the LO2 circulation to be reduced, affecting stability. If sufficient gas is generated within the pump due to heating, the pump may overspeed causing disintegration of the unit at engine start.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			CATASTROPHIC

COPIES TO: STRUCTURAL ____ MECHANICAL ____ MATERIALS ____ GSE ____ OTHER ____

AVIONICS ____ PROPULSION ____ VEHICLE SUPPORT ____ FACILITIES ____ PAYLOAD ____ SYS SAFETY X

ACTION RECOMMENDED:

Back-up systems should be incorporated to function if the primary system fails to maintain critical engine start parameters. The engine design should insure starting under expected conditions, if the conditions cannot be met the launch must be aborted.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				MARGINAL

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED ______

HAZARD ANALYSIS

PAGE 1 OF 1

DATE ______

REV ______

END ITEM ESS	SUBSYSTEM Pressurization	SUBSYSTEM IDENT NO. 13
OPERATION/PHASE Launch/Ascent		OP. IDENT. NO. B
HAZARD GROUP Reduced Integrity Of Structure Or Equipment		HAZARD GRP. CODE 2
REFERENCES FMEA 2.4B		AUTHORITY

HAZARD DESCRIPTION/ EFFECTS

Loss of ullage pressure within the LH2 tank to less than 27.5 psig at Max Q can cause structural failure due to the dynamic loads. This could be caused by low prepressurization prior to liftoff which decays below 30.6 PSIA due to LH2 cooling of the ullage, inadvertent operation of the vent valve (LH2) prior to T+70 sec, or faulty switching of the vent valves to the Low mode band (25.0 - 27.0 psig).

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			CATASTROPHIC

COPIES TO: STRUCTURAL ____ MECHANICAL ____ MATERIALS ____ GSE ____ OTHER ____

AVIONICS ____ PROPULSION ____ VEHICLE SUPPORT ____ FACILITIES ____ PAYLOAD ____ SYS SAFETY X

ACTION RECOMMENDED:

Design pressure within the LH2 tank should be a condition of launch, with launch abort required if the pressure is too low. The vent feature of the vent/relief valves should be automatically locked out during max Q to ~~prevent inadv~~ertant actuation.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				MARGINAL

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED

HAZARD ANALYSIS

PAGE ____ OF ____
DATE
REV

END ITEM ESS	SUBSYSTEM Pressurization	SUBSYSTEM IDENT NO. 13
OPERATION/PHASE Launch/Ascent		OP. IDENT. NO. B
HAZARD GROUP Loss of thrust		HAZARD GRP. CODE 7
REFERENCES FMEA 2.4B, 2.5B		AUTHORITY

HAZARD DESCRIPTION/ EFFECTS The loss of thrust prior to separation from the Booster could be caused by inadvertent opening of the dual parallel main tank vent valves or propellant tank fill valves. Either could result in loss of mission. Further, the failure to start ESS engines could possibly cause structural impact between the ESS and booster's vertical stabilizer during the separation maneuver. This impact could cause loss of crew and vehicle through loss of landing control.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			Catastrophic

COPIES TO: STRUCTURAL ____ MECHANICAL ____ MATERIALS ____ GSE ____ OTHER ____

AVIONICS ____ PROPULSION ____ VEHICLE SUPPORT ____ FACILITIES ____ PAYLOAD ____ SYS SAFETY X

ACTION RECOMMENDED: To prevent inadvertent actuation of the vent valves the actuation system should be locked out during those mission phases that do not require venting. The actuation energy required to open propellant fill valves should be external to the ESS.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				Marginal

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED ______

HAZARD ANALYSIS

PAGE ____ OF ____
DATE ______
REV ______

END ITEM ESS	SUBSYSTEM Structural	SUBSYSTEM IDENT NO. 5
OPERATION/PHASE Launch/Ascent		OP. IDENT. NO. B
HAZARD GROUP Reduced integrity of structure and equipment		HAZARD GRP. CODE 2
REFERENCES FMEA 2.4B		AUTHORITY

HAZARD DESCRIPTION/ EFFECTS During the mated ascent, failure of the heatshield for the engine compartment could create a hazard at ESS main engine start in that circulation into the thrust structure area could be expected. The impingement of the circulated hot gasses could damage lines, wiring and possibly destroy the OMS tanks insulation causing excess gassing or tank failure. Fragmentation from this possible explosion in the proximity of the booster could possibly damage the booster capability to land safely.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			Catastrophic

COPIES TO: STRUCTURAL ____ MECHANICAL ____ MATERIALS ____ GSE ____ OTHER ____

AVIONICS ____ PROPULSION ____ VEHICLE SUPPORT ____ FACILITIES ____ PAYLOAD ____ SYS SAFETY ____

ACTION RECOMMENDED: The heat shield installation crew should be trained in the correct installation methods and be guided by procedural controls. After installation the heat shield should be inspected by a group that is independent of the installation crew.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				MARGINAL

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED ______

HAZARD ANALYSIS

PAGE ____ OF ____
DATE ______
REV ______

END ITEM Booster/ESS | **SUBSYSTEM** Mechanical Avionics | **SUBSYSTEM IDENT NO.** 4/1

OPERATION/PHASE Launch/Ascent | **OP. IDENT. NO.** B

HAZARD GROUP Reduced integrity of structure or equipment | **HAZARD GRP. CODE** 2

REFERENCES FMEA 2.4B | **AUTHORITY**

HAZARD DESCRIPTION/ EFFECTS

Premature (prior to 50% ESS engine thrust) activation of the signal to the explosive bolts in the four vertical links in the Booster/ESS separation device or out of sequence firing of the explosive bolts restraining the ESS to the rotating links could cause premature separation resulting in potential impact between the Booster and ESS. This hazard could be initiated by a failure in the main computer system.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			Catastrophic

COPIES TO: STRUCTURAL ____ MECHANICAL ____ MATERIALS ____ GSE ____ OTHER ____

AVIONICS ____ PROPULSION ____ VEHICLE SUPPORT ____ FACILITIES ____ PAYLOAD ____ SYS SAFETY X

ACTION RECOMMENDED:

Critical staging signals should be performed by an automatic sequencer with secondary capability that is automatically switched in should the primary capability fail.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				Marginal

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED ______

HAZARD ANALYSIS

PAGE ____ OF ____

DATE ______

REV ______

END ITEM ESS	SUBSYSTEM Mechanical	SUBSYSTEM IDENT NO. 4
OPERATION/PHASE Launch/Ascent		OP. IDENT. NO. B
HAZARD GROUP Loss of attitude control		HAZARD GRP. CODE 10
REFERENCES FMEA 2.4B		AUTHORITY

HAZARD DESCRIPTION/ EFFECTS In the case where abort separation occurs in the atmospheric environment early in the launch phase, a hazard of aerodynamic instability in the ESS/propellant payload could exist. This instability could possibly lead to structural failure, fire, explosion or impact with the booster. If instability cannot be controlled, the possibility of fragmentation penetration and overpressures could be expected on the Booster.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			Catastrophic

COPIES TO: STRUCTURAL ____ MECHANICAL ____ MATERIALS ____ GSE ____ OTHER ____

AVIONICS ____ PROPULSION ____ VEHICLE SUPPORT ____ FACILITIES ____ PAYLOAD ____ SYS SAFETY X

ACTION RECOMMENDED: **The RCS** of the ESS should have secondary capability to provide attitude control if the primary mode fails during the critical period of ESS/Booster separation and during the periods when the ESS will be near any manned vehicle.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				Marginal

140

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED

HAZARD ANALYSIS

PAGE ____ OF ____

DATE ____

REV ____

END ITEM Booster/ESS	SUBSYSTEM Avionics	SUBSYSTEM IDENT NO. 1
OPERATION/PHASE Launch/Ascent - Perform Booster/ESS staging		OP. IDENT. NO. B
HAZARD GROUP Impact		HAZARD GRP. CODE 9
REFERENCES FMEA 2.5B		AUTHORITY

HAZARD DESCRIPTION/ EFFECTS During staging, failure of the Avionics computer to maintain separation flight paths, errors or failure of the main computer to initiate separation device explosive bolts, or loss of ESS engine thrust below 50% thrust level could establish a condition which could possible result in impact of the ESS with the Booster. Impact area would possibly be in the Booster vertical stabilizer area creating control problems for booster descent and landing.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			Catastrophic

COPIES TO: STRUCTURAL ____ MECHANICAL ____ MATERIALS ____ GSE ____ OTHER ____

AVIONICS ____ PROPULSION ____ VEHICLE SUPPORT ____ FACILITIES ____ PAYLOAD ____ SYS SAFETY X

ACTION RECOMMENDED:

To minimize separation damage to the booster the attach fitting of the ESS should include aft rotating links and emergency deploy maneuvers should be performed by the booster to provide optimum distance between booster and ESS.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				Marginal

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED ______

HAZARD ANALYSIS

PAGE ____ OF ____
DATE ______
REV ______

END ITEM Booster-ESS	SUBSYSTEM Avionics	SUBSYSTEM IDENT NO. 1
OPERATION/PHASE Launch/Ascent - Perform Booster/ESS staging		OP. IDENT. NO. B
HAZARD GROUP Loss of thrust		HAZARD GRP. CODE 7
REFERENCES FMEA 2.5B		AUTHORITY

HAZARD DESCRIPTION/ EFFECTS Booster engine throttling for separation is initiated by the Booster near-depletion signal from the LO_2 sensor. Failure of the main computer to receive this signal or failure in the LO_2 sensor to provide this signal will withhold the capability to start the ESS main engines automatically for initiation of the separation sequence. This situation would require emergency separation action by the crew. Failure of immediate action could lead to potential hazards associated with separation control and impact with the booster.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			Catastrophic

COPIES TO: STRUCTURAL ____ MECHANICAL ____ MATERIALS ____ GSE ____ OTHER ____

AVIONICS ____ PROPULSION ____ VEHICLE SUPPORT ____ FACILITIES ____ PAYLOAD ____ SYS SAFETY X

ACTION RECOMMENDED: The near-depletion sensors and associated electronics that control critical separation sequences should have back-up capability that would function in the event the primary systems fail.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				Marginal

142

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED ______

HAZARD ANALYSIS

PAGE ____ OF ____
DATE ______
REV ______

END ITEM ESS	SUBSYSTEM Avionics	SUBSYSTEM IDENT NO. 1
OPERATION/PHASE Launch/Ascent		OP. IDENT. NO. B
HAZARD GROUP Fire/Explosion/Implosion		HAZARD GRP. CODE 1
REFERENCES FMEA 2.5B		AUTHORITY

HAZARD DESCRIPTION/ EFFECTS The propellant dispersion system on the ESS is armed on the ESS, after staging from the Booster, by the Range Safety System Controller. Premature firing at the time of arming through failure in the controller which allows capacitor charging and trigger circuit completion to the **exploding bridge wire (EBW), could cause the tank destruct assemblies to function. This could present a hazard to the Booster which could cause loss of the crew if occurrence is immediately after separation or before adequate separation of the Booster/ESS had been achieved.**

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			Catastrophic

COPIES TO: STRUCTURAL ____ MECHANICAL ____ MATERIALS ____ GSE ____ OTHER ____

AVIONICS ____ PROPULSION ____ VEHICLE SUPPORT ____ FACILITIES ____ PAYLOAD ____ SYS SAFETY X

ACTION RECOMMENDED: The ESS propellant dispersion system should require separate and distinct commands to arm and to fire the EBW units. Electrical failures that could contribute to inadvertent commands should be minimized in the design. The design should receive extensive development and flight testing prior to use to minimize inadvertent commands being propogated.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				Marginal

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED ____

HAZARD ANALYSIS

PAGE ____ OF ____
DATE ____
REV ____

END ITEM ESS	SUBSYSTEM Avionics	SUBSYSTEM IDENT NO. 1
OPERATION/PHASE Launch/Ascent		OP. IDENT. NO. B
HAZARD GROUP Loss of attitude control		HAZARD GRP. CODE 10
REFERENCES FMEA 2.5B		AUTHORITY

HAZARD DESCRIPTION/EFFECTS Loss of the data control management computer output or marginal signals which cause loss of reduced stabilization control, presents hazards to populated land masses or shipping through loss of abort capability, by inability to attain correct insertion position for retro firing and entry.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			Catastrophic

COPIES TO: STRUCTURAL ____ MECHANICAL ____ MATERIALS ____ GSE ____ OTHER ____

AVIONICS ____ PROPULSION ____ VEHICLE SUPPORT ____ FACILITIES ____ PAYLOAD ____ SYS SAFETY X

ACTION RECOMMENDED:

The computer should have back-up capability that would provide full operational functions in the event the primary system failed.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				Marginal

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED ______

HAZARD ANALYSIS

PAGE ____ OF ____

DATE ______

REV ______

END ITEM Booster	SUBSYSTEM Propellant	SUBSYSTEM IDENT NO. 11
OPERATION/PHASE Launch/Ascent - Perform Booster/ESS staging		OP. IDENT. NO. B
HAZARD GROUP Loss of thrust		HAZARD GRP. CODE 7
REFERENCES FMEA 2.5B		AUTHORITY

HAZARD DESCRIPTION/ EFFECTS The stage sequence controller provides sequencing of stage functions including the LH_2 recirculation return valve and tank isolation valve. Failure to sequence these valves "open" could cause loss of thrust (engine start). The LH_2 recirculation system is turned on 10 minutes prior to engine start to effect engine conditioning, while the isolation valve controls start of flow through the fuel system. Thus no thrust or possible loss of engines could result from this failure. Should engine blow-up occur at staging, fragmentation hazards would be experienced by the Booster and crew.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			Catastrophic

COPIES TO: STRUCTURAL ____ MECHANICAL ____ MATERIALS ____ GSE ____ OTHER ____

AVIONICS ____ PROPULSION ____ VEHICLE SUPPORT ____ FACILITIES ____ PAYLOAD ____ SYS SAFETY X

ACTION RECOMMENDED: Provide spring loaded, normally open valves for these applications, which is the fail-safe condition. Provide inhibit circuits which will prevent the valves from being electrically actuated until the appropriate time in the sequence.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				Marginal

145

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED

HAZARD ANALYSIS

PAGE ___ OF ___
DATE ___
REV ___

END ITEM Booster	SUBSYSTEM Structural	SUBSYSTEM IDENT NO. 5
OPERATION/PHASE Launch/Ascent - Perform Booster/ESS staging		OP. IDENT. NO. B
HAZARD GROUP Heat/Temperature		HAZARD GRP. CODE 6
REFERENCES FMEA 2.5B		AUTHORITY

HAZARD DESCRIPTION/ EFFECTS The Data and Control Management (DCM) system provides configuration and sequence control, processes guidance and navigation algorithms, etc. Immediately after booster separation of the ESS, any deviation of the booster/ESS flight path from programmed trajectories could subject the booster crew with the hazard of heat/temperature if the booster were directed into the path of main engine exhaust or plume in the area of the booster crew/cockput area. This could be caused by an undesired pitching movement on either vehicle.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			Catastrophic

COPIES TO: STRUCTURAL ___ MECHANICAL ___ MATERIALS ___ GSE ___ OTHER ___

AVIONICS ___ PROPULSION ___ VEHICLE SUPPORT ___ FACILITIES ___ PAYLOAD ___ SYS SAFETY X

ACTION RECOMMENDED: The ESS DCM system should be provided with alternates to provide navigation and control in the event that the primary system fails. To be used with the manned booster the operational levels of the ESS must not degrade the manrating of the manned element.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				Marginal

CONTRACT NAS8-27692
LOCATION/SITE INVOLVED

HAZARD ANALYSIS

PAGE ___ OF ___
DATE ___
REV ___

END ITEM ESS	SUBSYSTEM Pressurization	SUBSYSTEM IDENT NO. 13
OPERATION/PHASE Launch/Ascent, Achieve mission orbit		OP. IDENT. NO. B
HAZARD GROUP Loss of thrust		HAZARD GRP. CODE 7
REFERENCES FMEA 2.6B		AUTHORITY

HAZARD DESCRIPTION/ EFFECTS In the event the ESS vent valves fail "open", the main engines would fail to start or fail to continue operation if started, due to loss of stage tank pressure. This could lead to abort which may impact the ESS in a populated land mass, and if occurring immediately after separation could cause conditions which could result in the loss of the booster and crew.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			Catastrophic

COPIES TO: STRUCTURAL ___ MECHANICAL ___ MATERIALS ___ GSE ___ OTHER ___

AVIONICS ___ PROPULSION ___ VEHICLE SUPPORT ___ FACILITIES ___ PAYLOAD ___ SYS SAFETY X

ACTION RECOMMENDED: A single order failure mode exists for both propellant tank vent valves on the ESS. A study should be conducted to determine if this risk should be accepted because of the flight history of the S-II or if additional redundancy in the vent system is justified.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				Critical

147

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED

HAZARD ANALYSIS

PAGE ____ OF ____
DATE ____
REV ____

END ITEM ESS	SUBSYSTEM Pressurization	SUBSYSTEM IDENT NO. 13
OPERATION/PHASE Launch/Ascent - Achieve mission orbit		OP. IDENT. NO. B
HAZARD GROUP Reduced integrity of structure or equipment		HAZARD GRP. CODE 2
REFERENCES FMEA 2.6B		AUTHORITY

HAZARD DESCRIPTION/ EFFECTS The GH_2 pressurizing the LH_2 tank during ESS burn enters the tank at $530^{o} \pm 130R$. At the end of ESS burn the LH_2 forward bulkhead is at its warmest condition. If the LH_2 tank pressure exceeds 27.5 psia the structural integrity could be lost. This hazard could be initiated by failure of the step modes going from high mode vent valve operation to low mode range, i.e., 27.5-29.5 psig and 25.0 to 27.0 psig respectively. Failure to effect low mode vent valve operation before ESS ECO could fail the structure.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			Catastrophic

COPIES TO: STRUCTURAL ____ MECHANICAL ____ MATERIALS ____ GSE ____ OTHER ____

AVIONICS ____ PROPULSION ____ VEHICLE SUPPORT ____ FACILITIES ____ PAYLOAD ____ SYS SAFETY X

ACTION RECOMMENDED: A single failure point exists in the ESS pressurization system if both vent valves are commanded to the low mode with a single circuit and a single electrical signal. Separate circuits and separate power sources should command the vents to the low mode to provide alternate capability.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				Critical

148

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED

HAZARD ANALYSIS

PAGE ____ OF ____

DATE ____

REV ____

END ITEM ESS	SUBSYSTEM Propulsion	SUBSYSTEM IDENT NO. 2
OPERATION/PHASE Launch/Ascent - Achieve mission orbit		OP. IDENT. NO. B
HAZARD GROUP Loss of thrust		HAZARD GRP. CODE 7
REFERENCES FMEA 2.6B		AUTHORITY

HAZARD DESCRIPTION/ EFFECTS A vent valve provides control of gas exhausting from the heat exchanger/turbo-pump gas generators through either the propulsive vent or the non-propulsive vent. A hazard is created if one of the two valves used per stage fails in the propulsive vent position. The constant thrust developed would cause demands on the attitude control propulsion system to maintain vehicle attitude. Early depletion of propellants would lead to loss of thrust for the mission duration if undetected and corrected.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			Critical

COPIES TO: STRUCTURAL ____ MECHANICAL ____ MATERIALS ____ GSE ____ OTHER ____

AVIONICS ____ PROPULSION ____ VEHICLE SUPPORT ____ FACILITIES ____ PAYLOAD ____ SYS SAFETY X

ACTION RECOMMENDED: Exhaust gas vent controls should have alternate capability to be used in the event the primary mode fails.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				Marginal

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED ____

HAZARD ANALYSIS

PAGE ____ OF ____
DATE ____
REV ____

END ITEM ESS	SUBSYSTEM Propulsion	SUBSYSTEM IDENT NO. 2
OPERATION/PHASE Launch/Ascent - Achieve mission orbit		OP. IDENT. NO. B
HAZARD GROUP Loss of thrust, Fire/Explosion		HAZARD GRP. CODE 7, 1
REFERENCES FMEA 2.6B		AUTHORITY

HAZARD DESCRIPTION/ EFFECTS The hazard from loss of thrust on the OMS engines can be initiated by (1) OMS engine thrust chamber feed valve (O_2 and H_2) failing open or failing to close, (2) inoperative pump/turbine or gas generator, (3) valve failures and (4) turbo-pump gas generator O_2 and H_2 pressure regulator regulating too high or low. In cases (1) thru (3) the OMS engine thrust is lost. In case (4) a time dependent fire/explosion due to improper mixture ratio is possible.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			Catastrophic

COPIES TO: STRUCTURAL ____ MECHANICAL ____ MATERIALS ____ GSE ____ OTHER ____

AVIONICS ____ PROPULSION ____ VEHICLE SUPPORT ____ FACILITIES ____ PAYLOAD ____ SYS SAFETY _x_

ACTION RECOMMENDED: (1), (2), (3) Design single OMS engine to achieve mission in case one fails, and (4) Provide back-up capability in case of primary regulator failure to maintain correct pressure.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				Marginal

150

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED ______

HAZARD ANALYSIS

PAGE ____ OF ____
DATE ______
REV ______

END ITEM: ESS	SUBSYSTEM: Avionics	SUBSYSTEM IDENT NO. 1
OPERATION/PHASE: Orbital - Perform rendezvous maneuvers		OP. IDENT. NO. C
HAZARD GROUP: Loss of communication		HAZARD GRP. CODE 13
REFERENCES: FMEA 3.1B		AUTHORITY

HAZARD DESCRIPTION/ EFFECTS Failure of the communications subsystem switching unit up/down data link creates hazards for the ESS. Down data is not critical however loss of up data link may preclude ranging data and rendezvous commands from reaching the ESS computer, resulting in serious position errors or loss of retro-fire commands for deorbiting. Loss of the latter command would result in uncontrolled reentry of the ESS upon orbit decay.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			Critical

COPIES TO: STRUCTURAL ____ MECHANICAL ____ MATERIALS ____ GSE ____ OTHER ____

AVIONICS ____ PROPULSION ____ VEHICLE SUPPORT ____ FACILITIES ____ PAYLOAD ____ SYS SAFETY X

ACTION RECOMMENDED:

Critical communications system controls should be provided with alternate capability to be used in case of the failure of the initial system.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				Marginal

151

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED ______

HAZARD ANALYSIS

PAGE ____ OF ____
DATE ______
REV ______

END ITEM ESS	SUBSYSTEM Avionics	SUBSYSTEM IDENT NO. 1
OPERATION/PHASE Orbital-Perform rendezvous maneuvers		OP. IDENT. NO. C
HAZARD GROUP Loss of attitude control		HAZARD GRP. CODE 10
REFERENCES FMEA 3.1B FMEA 3.2B		AUTHORITY

HAZARD DESCRIPTION/ EFFECTS Excessive use/loss of propellants for the ACPS could cause failure to achieve stability of the ESS needed for the user to effect a docking with the propellant logistic tank. This loss could be associated with valve failure (propulsive vent valve) in the propulsive vent position resulting in increased fuel consumption to maintain vehicle attitude.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			Critical

COPIES TO: STRUCTURAL ____ MECHANICAL ____ MATERIALS ____ GSE ____ OTHER ____

AVIONICS ____ PROPULSION ____ VEHICLE SUPPORT ____ FACILITIES ____ PAYLOAD ____ SYS SAFETY X

ACTION RECOMMENDED: Exhaust gas vent controls should have alternate capability to be used in the event the primary mode fails.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				Marginal

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED ______

HAZARD ANALYSIS

PAGE ____ OF ____
DATE ______
REV ______

END ITEM ESS

SUBSYSTEM Structural

SUBSYSTEM IDENT NO. 5

OPERATION/PHASE Orbital-Perform rendezvous maneuvers

OP. IDENT. NO. C

HAZARD GROUP Impact

HAZARD GRP. CODE 9

REFERENCES FMEA 3.1B

AUTHORITY

HAZARD DESCRIPTION/EFFECTS Failure to detect orbital debris which is in the flight path of the ESS or on an intercept course, could impact the ESS. Since no detection equipment is available for alerting the ground operational center, impact could occur without taking evasive action. The size and relative velocities could create an impact which could cause loss of the mission or decrease the ESS capability to marginal performance.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			Critical

COPIES TO: STRUCTURAL ____ MECHANICAL ____ MATERIALS ____ GSE ____ OTHER ____

AVIONICS ____ PROPULSION ____ VEHICLE SUPPORT ____ FACILITIES ____ PAYLOAD ____ SYS SAFETY X

ACTION RECOMMENDED: The erosion barrier should be sized to resist the impact of meteorites and debris of one gram mass and smaller. The impact of debris of larger mass could have catastrophic results.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				Critical

153

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED ______

HAZARD ANALYSIS

PAGE ____ OF ____
DATE ______
REV ______

END ITEM ESS/Prop. Module/CIS	SUBSYSTEM Structural	SUBSYSTEM IDENT NO. 5
OPERATION/PHASE Orbital-Prepare for user docking		OP. IDENT. NO. C
HAZARD GROUP Impact		HAZARD GRP. CODE 9
REFERENCES FMEA 3.2B		AUTHORITY

HAZARD DESCRIPTION/ EFFECTS Impact, resulting from improper docking alignment between the CIS and ESS, could cause structural damage to the docking structure or cause impact between the the structure and the line interconnect fixtures. This would result in potential damage to the structure involved to the point where the reduced integrity made docking or propellant transfer impossible. This impact may be accentuated by the sloshing fluids.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			Critical

COPIES TO: STRUCTURAL ____ MECHANICAL ____ MATERIALS ____ GSE ____ OTHER ____

AVIONICS ____ PROPULSION ____ VEHICLE SUPPORT ____ FACILITIES ____ PAYLOAD ____ SYS SAFETY X

ACTION RECOMMENDED:

The Active Docking Vehicle (CIS) should automatically control the final closing velocity/attitude of the docking maneuver within design limits.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				Marginal

154

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED ____

HAZARD ANALYSIS

PAGE ____ OF ____
DATE ____
REV ____

END ITEM ESS	SUBSYSTEM Avionics	SUBSYSTEM IDENT NO. 1
OPERATION/PHASE Orbital - Prepare for user docking		OP. IDENT. NO. C
HAZARD GROUP Loss of communication		HAZARD GRP. CODE 13
REFERENCES FMEA 3.2B		AUTHORITY

HAZARD DESCRIPTION/ EFFECTS Loss of TV docking aids or ranging transponder, could reduce the communication to ground control, thus rendering the operational data needed for management control lost or certainly reduced. This loss would reduce the integrity of the remote docking operation and possibly delay the mission.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			Critical

COPIES TO: STRUCTURAL ____ MECHANICAL ____ MATERIALS ____ GSE ____ OTHER ____

AVIONICS ____ PROPULSION ____ VEHICLE SUPPORT ____ FACILITIES ____ PAYLOAD ____ SYS SAFETY x

ACTION RECOMMENDED: Critical docking aids should have back up systems to provide docking data in the event the primary system fails. When critical data is lacking no attempt should be made to dock until repairs are made.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				Marginal

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED ______

HAZARD ANALYSIS

PAGE ____ OF ____
DATE ______
REV ______

END ITEM	SUBSYSTEM	SUBSYSTEM IDENT NO.
ESS/PROP.MOD/CIS	Pressurization	13

OPERATION/PHASE	OP. IDENT. NO.
Orbital - Prepare for user docking	C
HAZARD GROUP	**HAZARD GRP. CODE**
Contamination	3
REFERENCES	**AUTHORITY**
FMEA 3.2B	

HAZARD DESCRIPTION/EFFECTS Pressure relief through the propellant module vent valves during docking could cause the TV monitor lens to be contaminated with ice crystals, if a cloud formation occurs through which the TV monitor may pass during docking.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			Critical

COPIES TO: STRUCTURAL ____ MECHANICAL ____ MATERIALS ____ GSE ____ OTHER ____

AVIONICS ____ PROPULSION ____ VEHICLE SUPPORT ____ FACILITIES ____ PAYLOAD ____ SYS SAFETY x

ACTION RECOMMENDED: Procedural controls should be implemented to require that temporary loss of visual data from primary systems be acquired from redundant sources. If all visual data is lost the operation under way should be terminated and the active vehicle withdrawn until visual contact is restored.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				Marginal

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED ______

PAGE ____ OF ____
DATE ______
REV ______

HAZARD ANALYSIS

END ITEM ESS/CIS	SUBSYSTEM Structural	SUBSYSTEM IDENT NO. 5
OPERATION/PHASE Orbital - Prepare for transfer operation		OP. IDENT. NO. C
HAZARD GROUP Reduced integrity of structure or equipment		HAZARD GRP. CODE 2
REFERENCES FMEA 4.1B		AUTHORITY Project II, task II-3

HAZARD DESCRIPTION/ EFFECTS A hazard exists during preparation for transfer hookup when the line interconnect fixture meteoroid shield has not been retracted prior to docking. The hazard results in damage to the indexing probes as they are forced into the shield instead of the mating interconnect half. The effect of this damage would result in loss of capability to rigidize the interface for transfer line connection. This damage may also cause the index probe chain drive to break, rendering the system inoperative

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			Critical

COPIES TO: STRUCTURAL ____ MECHANICAL ____ MATERIALS ____ GSE ____ OTHER ____

AVIONICS ____ PROPULSION ____ VEHICLE SUPPORT ____ FACILITIES ____ PAYLOAD ____ SYS SAFETY x

ACTION RECOMMENDED: The meteoroid shield should be capable of being retracted before or after docking. Line hook-up should not be attempted before it can be verified that the shield has been retracted.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				Marginal

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED

PAGE ____ OF ____

DATE ____

REV ____

HAZARD ANALYSIS

END ITEM ESS/PROPELLANT TANK/CIS	SUBSYSTEM Mechanical	SUBSYSTEM IDENT NO. 4
OPERATION/PHASE Orbital - Prepare for transfer operation		OP. IDENT. NO. C
HAZARD GROUP Fire, explosion/ reduced integrity of structure or equipment		HAZARD GRP. CODE 1/2
REFERENCES FMEA 4.1B		AUTHORITY

HAZARD DESCRIPTION/ EFFECTS The continual flexing, shortening and compressing of the extension bellows on the line interconnect fixture fluid lines during operation could cause rupture from fatigue, stress or defective material. The failure if occurring during propellant transfer could cause localized fluid concentrations which may have a potential fire/explosion capability. If detected prior to fluid transfer, the failure would cause the operation to be terminated. Mechanism for the fire or explosion would be potential propellant mixing in the confined area of the interconnect fixture.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			Critical

COPIES TO: STRUCTURAL ____ MECHANICAL ____ MATERIALS ____ GSE ____ OTHER ____

AVIONICS ____ PROPULSION ____ VEHICLE SUPPORT ____ FACILITIES ____ PAYLOAD ____ SYS SAFETY x

ACTION RECOMMENDED: The service life (number of flexures) of the line interconnect bellows should be established in the design and development tests. The bellows should be replaced before it has exceeded its service life. Leak checks of lines and bellows should be performed before initiating propellant flow.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				Marginal

158

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED ______

HAZARD ANALYSIS

PAGE ____ OF ____

DATE ______

REV ______

END ITEM ESS-PROP. TANK-CIS	SUBSYSTEM Pressurization	SUBSYSTEM IDENT NO. 13
OPERATION/PHASE Orbital - Prepare for transfer operation		OP. IDENT. NO.
HAZARD GROUP Disturbance		HAZARD GRP. CODE 14
REFERENCES FMEA 4.1B		AUTHORITY

HAZARD DESCRIPTION/ EFFECTS

Leaking at the quick disconnect for the pressurization line will cause loss of pressurization and may act as a reaction vent to produce undesired movement of the vehicles. This could be caused by contamination or damaged seal.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			Critical

COPIES TO: STRUCTURAL ____ MECHANICAL ____ MATERIALS ____ GSE ____ OTHER ____

AVIONICS ____ PROPULSION ____ VEHICLE SUPPORT ____ FACILITIES ____ PAYLOAD ____ SYS SAFETY x

ACTION RECOMMENDED:

Secondary seals should be provided to inhibit leakage in case the primary seal fails. Consideration should be given to the incorporation of non-propulsive vent openings for residual or leaking gases.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				Marginal

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED ______

HAZARD ANALYSIS

PAGE ____ OF ____
DATE ______
REV ______

END ITEM ESS-Propellant tank	SUBSYSTEM Mechanical	SUBSYSTEM IDENT NO. 4
OPERATION/PHASE Orbital-Prepare for transfer operation		OP. IDENT. NO. C
HAZARD GROUP Fire/explosion/implosion		HAZARD GRP. CODE 1
REFERENCES FMEA 4.1B		AUTHORITY

HAZARD DESCRIPTION/ EFFECTS Failure of the propellant line isolation valve in the closed position presents no hazard; however, the ESS upon earth return with the loaded tank attached could be expected to be accompanied with a fire/explosion which may cause debris to be scattered over a wide footprint. This hazard also is produced if the probe extension drive fails to extend the fuel line probes.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			Critical

COPIES TO: STRUCTURAL ____ MECHANICAL ____ MATERIALS ____ GSE ____ OTHER ____

AVIONICS ____ PROPULSION ____ VEHICLE SUPPORT ____ FACILITIES ____ PAYLOAD ____ SYS SAFETY x

ACTION RECOMMENDED: Critical propellant transfer controls should have secondary control systems in case the primary mode fails. If the ESS must be de-orbited with a loaded propellant module attached, the de-orbit trajectory should be timed such that the footprint would be located in an open ocean area sufficiently large to accommodate the footprint.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				Critical

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED ______

HAZARD ANALYSIS

PAGE ____ OF ____
DATE ______
REV ______

END ITEM ESS/Prop. Tank/CIS	SUBSYSTEM Propulsion/Avionics	SUBSYSTEM IDENT NO. 2/1
OPERATION/PHASE Orbital - Transfer propellants		OP. IDENT. NO. C
HAZARD GROUP Loss of attitude control		HAZARD GRP. CODE 10
REFERENCES FMEA 4.2B		AUTHORITY

HAZARD DESCRIPTION/ EFFECTS Disturbance of propellants in the ESS, sloshing as a result of RCS stabilization firing, may be produced by the CIS when most of the propellant has been transferred out of the propellant tank into the CIS. Loss of sensitivity causing overreaction or intermittent operation of the RCS could cause an unstable condition during transfer operations within the ESS tanks. This disturbance coupled with the dynamics of the configuration may cause loss of attitude control.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			Catastrophic

COPIES TO: STRUCTURAL ____ MECHANICAL ____ MATERIALS ____ GSE ____ OTHER ____

AVIONICS ____ PROPULSION ____ VEHICLE SUPPORT ____ FACILITIES ____ PAYLOAD ____ SYS SAFETY X

ACTION RECOMMENDED: Slosh dampening devices should be incorporated into both the CIS and ESS. Secondary controls for the RCS should be incorporated to provide stabilization in the event the primary controls fail.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				Critical

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED ______

PAGE ____ OF ____

DATE ______

REV ______

HAZARD ANALYSIS

END ITEM
ESS/Prop Tank/CIS

SUBSYSTEM
Propellant

SUBSYSTEM IDENT NO.
11

OPERATION/PHASE
Orbital-Transfer propellants

OP. IDENT. NO.
C

HAZARD GROUP
Reduced integrity of structure or equipment

HAZARD GRP. CODE
2

REFERENCES
FMEA 4.2B

AUTHORITY

HAZARD DESCRIPTION/ EFFECTS

During childown of lines and CIS tankage, stressing of the system could cause structural failure. This could be expected to occur if childown of the system is attempted too rapidly.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			Critical

COPIES TO: STRUCTURAL ____ MECHANICAL ____ MATERIALS ____ GSE ____ OTHER ____

AVIONICS ____ PROPULSION ____ VEHICLE SUPPORT ____ FACILITIES ____ PAYLOAD ____ SYS SAFETY X

ACTION RECOMMENDED:

Automatic or procedural flow controls should be incorporated in the transfer system to prevent maximum propellant flow until the user vehicle was cooled down to design limitations.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				Marginal

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED ______

HAZARD ANALYSIS

PAGE ____ OF ____
DATE ______
REV ______

END ITEM Prop Tank/CIS	SUBSYSTEM Propellant	SUBSYSTEM IDENT NO. 11
OPERATION/PHASE Orbital - Transfer propellants		OP. IDENT. NO. C
HAZARD GROUP Fire/Explosion/Implosion		HAZARD GRP. CODE
REFERENCES FMEA 4.2B		AUTHORITY

HAZARD DESCRIPTION/ EFFECTS It can be expected that any LH_2 **propellant leakage, which is mixed with** leaking LO_2, into a confined area could cause explosion or fire. This confinement need only be to the extent that the pressure exceeds 2mm Hg and have a source of ignition either electrical or catalytic.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			Critical

COPIES TO: STRUCTURAL ____ MECHANICAL ____ MATERIALS ____ GSE ____ OTHER ____

AVIONICS ____ PROPULSION ____ VEHICLE SUPPORT ____ FACILITIES ____ PAYLOAD ____ SYS SAFETY X

ACTION RECOMMENDED: To prevent leaking propellants from building up ignition pressures the possible leak sources should be exposed to space vacuum and not enclosed.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				Marginal

163

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED ______

HAZARD ANALYSIS

PAGE ____ OF ____
DATE ______
REV ______

END ITEM ESS/Prop Tank/CIS	SUBSYSTEM Avionics	SUBSYSTEM IDENT NO. 1
OPERATION/PHASE Orbital - Transfer propellants		OP. IDENT. NO. C
HAZARD GROUP Reduced integrity of structure or equipment		HAZARD GRP. CODE 2
REFERENCES FMEA 4.2B		AUTHORITY

HAZARD DESCRIPTION/ EFFECTS Loss of grounding/bonding within the vehicles configuration during transfer of propellants, could cause static electrical discharge between vehicles, systems or internal structural groups. This could be caused by isolation of systems through failure of the bonding between systems, such that potential charge buildup will occur to cause discharge across the systems.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			Critical

COPIES TO: STRUCTURAL ____ MECHANICAL ____ MATERIALS ____ GSE ____ OTHER ____

AVIONICS ____ PROPULSION ____ VEHICLE SUPPORT ____ FACILITIES ____ PAYLOAD ____ SYS SAFETY X

ACTION RECOMMENDED:

Multiple grounding paths should be provided to insure the continuity of the electrical bond. Grounding pins in electrical connectors should be the first ones made and the last ones broken.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				Marginal

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED

HAZARD ANALYSIS

PAGE ___ OF ___
DATE ___
REV ___

END ITEM Prop Tank/CIS	SUBSYSTEM Propellant	SUBSYSTEM IDENT NO. 11
OPERATION/PHASE Orbital - Transfer propellants		OP. IDENT. NO. C
HAZARD GROUP Reduced integrity of structure or equipment		HAZARD GRP. CODE 2
REFERENCES FMEA 4.2B		AUTHORITY

HAZARD DESCRIPTION/ EFFECTS Failure of the electronics system of the flow meter during propellant transfer would result in loss of intelligence as to how much propellant has been transferred. This failure could result in underfill or overfill of the CIS tanks which could affect adversely the CIS mission.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			Critical

COPIES TO: STRUCTURAL ___ MECHANICAL ___ MATERIALS ___ GSE ___ OTHER ___

AVIONICS ___ PROPULSION ___ VEHICLE SUPPORT ___ FACILITIES ___ PAYLOAD ___ SYS SAFETY X

ACTION RECOMMENDED: To insure the maintenance of an accurate propellant inventory both the supplier and user tanks should be provided with propellant quantity measuring devices that would supplement or replace the flow meter data.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				Marginal

165

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED ____

HAZARD ANALYSIS

PAGE ____ OF ____

DATE ____

REV ____

END ITEM ESS/Prop Tank/CIS	SUBSYSTEM Propellant/Structural	SUBSYSTEM IDENT NO. 11/5
OPERATION/PHASE Orbital - Transfer propellants		OP. IDENT. NO. C
HAZARD GROUP Reduced integrity of structure or equipment		HAZARD GRP. CODE 2
REFERENCES FMEA 4.2B		AUTHORITY

HAZARD DESCRIPTION/ EFFECTS If rotational application of gravity is used for propellant transfer and the CG falls within the CIS during transfer of propellants, it could be expected that the pressurization system compressor may be slugged with 2 phase flow from the liquid/gas return flow from the ullage area. This would essentially stop the transfer operation and cause damage/loss of the pressurization system. Linear acceleration for propellant settling does not create this hazard.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			Critical

COPIES TO: STRUCTURAL ____ MECHANICAL ____ MATERIALS ____ GSE ____ OTHER ____

AVIONICS ____ PROPULSION ____ VEHICLE SUPPORT ____ FACILITIES ____ PAYLOAD ____ SYS SAFETY X

ACTION RECOMMENDED: If rotational acceleration is used to provide propellant settling the dynamics of the entire configuration should be studied to insure that no liquid is passed through the ullage gas exchange lines. Consideration should be given to providing a liquid/gas separator in supply line to gas compressor.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				Marginal

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED

HAZARD ANALYSIS

PAGE ____ OF ____
DATE ____
REV ____

END ITEM ESS/Prop Tank-CIS	SUBSYSTEM Propulsion	SUBSYSTEM IDENT NO. 2
OPERATION/PHASE Orbital-terminate transfer operation		OP. IDENT. NO. C
HAZARD GROUP Reduced integrity of structure or equipment		HAZARD GRP. CODE 2
REFERENCES FMEA 4.3B		AUTHORITY

HAZARD DESCRIPTION/ EFFECTS At termination of propellant transfer and prior to separation, failure to purge lines of fluids could present hazards. These hazards are caused by cryogenic fluids being locked up in line sections. Lack of pressure relief can destroy the line section due to fluid expansion.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS Critical

COPIES TO: STRUCTURAL ____ MECHANICAL ____ MATERIALS ____ GSE ____ OTHER ____

AVIONICS ____ PROPULSION ____ VEHICLE SUPPORT ____ FACILITIES ____ PAYLOAD ____ SYS SAFETY X

ACTION RECOMMENDED: Pressure relief capability should be provided in sections of propellant lines where it is possible to trap liquid propellants.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				Marginal

167

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED ______

HAZARD ANALYSIS

PAGE ____ OF ____
DATE ______
REV ______

END ITEM ESS/Tank	SUBSYSTEM Mechanical	SUBSYSTEM IDENT NO. 4
OPERATION/PHASE Orbital - Terminate transfer operation		OP. IDENT. NO. C
HAZARD GROUP Reduced integrity of structure or equipment		HAZARD GRP. CODE 2
REFERENCES FMEA 4.3B		AUTHORITY

HAZARD DESCRIPTION/ EFFECTS A pressurization leak through the QD during separation of the line interconnect fixture could reduce the delivery tankage pressure below ground ambient. It is assumed no shutoff valve is installed because of weight penalty. During orbital operation no hazard is created however upon reentry with the ESS the tank could implode and explode with the potential effect of changing the trajectory of the entering mass. The multitude of pieces may change the anticipated fragmentation pattern within the footprint, depending on the altitude of the explosion.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			Critical

COPIES TO: STRUCTURAL ____ MECHANICAL ____ MATERIALS ____ GSE ____ OTHER ____

AVIONICS ____ PROPULSION ____ VEHICLE SUPPORT ____ FACILITIES ____ PAYLOAD ____ SYS SAFETY X

ACTION RECOMMENDED: When the ESS is de-orbited the de-orbit trajectory should be timed so that enough open ocean is available to accommodate the footprint.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				Marginal

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED

HAZARD ANALYSIS

PAGE ____ OF ____
DATE ____
REV ____

END ITEM ESS/Prop Tank/CIS	SUBSYSTEM Mechanical	SUBSYSTEM IDENT NO. 4
OPERATION/PHASE Orbital-Terminate transfer operation		OP. IDENT. NO. C
HAZARD GROUP Reduced integrity of structure or equipment		HAZARD GRP. CODE 2
REFERENCES FMEA 4.3B		AUTHORITY

HAZARD DESCRIPTION/ EFFECTS Mechanical failure of the retraction mechanism for indexing probe retraction could preclude normal separation of the CIS and propellant tank/ESS. This could be due to binding, failure of the drive chain or failure of the motor or power thereto. Any one of the three indexing probes which does not retract could cause the hazard.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			Critical

COPIES TO: STRUCTURAL ____ MECHANICAL ____ MATERIALS ____ GSE ____ OTHER ____

AVIONICS ____ PROPULSION ____ VEHICLE SUPPORT ____ FACILITIES ____ PAYLOAD ____ SYS SAFETY X

ACTION RECOMMENDED: Critical separation system components and controls should have back-up systems that would effect separation in the event the primary system failed.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				Marginal

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED

HAZARD ANALYSIS

PAGE ____ OF ____
DATE
REV

END ITEM ESS/Prop Tank/CIS	SUBSYSTEM Mec	SUBSYSTEM IDENT NO. 4
OPERATION/PHASE Orbital - Undock user from ESS-Prop Tank		OP. IDENT. NO. C
HAZARD GROUP Reduced integrity of structure or equipment		HAZARD GRP. CODE 2
REFERENCES FMEA 6.1B		AUTHORITY

HAZARD DESCRIPTION/ EFFECTS Failure of the latching devices, on the docking ring, to unlatch could preclude the CIS from undocking normally. This failure could cause loss of the entire configuration if emergency separation could not be effected. While no hazards to personnel exist, separation by explosive charge could render the CIS mission delayed until maintenance EVA had made the necessary repairs.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			Critical

COPIES TO: STRUCTURAL ____ MECHANICAL ____ MATERIALS ____ GSE ____ OTHER ____

AVIONICS ____ PROPULSION ____ VEHICLE SUPPORT ____ FACILITIES ____ PAYLOAD ____ SYS SAFETY X

ACTION RECOMMENDED: Explosive or other emergency separation devices should be designed to allow the CIS to complete its mission before repairs to separation system would have to be made.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				Marginal

170

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED

HAZARD ANALYSIS

PAGE ___ OF ___

DATE ___

REV ___

END ITEM ESS/Prop Tank/CIS — SUBSYSTEM Mechanical	SUBSYSTEM IDENT NO. 4
OPERATION/PHASE Orbital-Undock user from ESS/Prop Tank	OP. IDENT. NO. C
HAZARD GROUP Disturbance	HAZARD GRP. CODE 14
REFERENCES FMEA 6.1B	AUTHORITY

HAZARD DESCRIPTION/ EFFECTS In the event where release of the docking ring is commanded and one locking lug hangs up so that total release is not effected, movement initiated by the CIS thrusters for translation could import a motion into the CIS and ESS/Prop tank which would cause sloshing to occur thereby imposing disturbances into the partially separated configuration.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			Catastrophic

COPIES TO: STRUCTURAL ___ MECHANICAL ___ MATERIALS ___ GSE ___ OTHER ___

AVIONICS ___ PROPULSION ___ VEHICLE SUPPORT ___ FACILITIES ___ PAYLOAD ___ SYS SAFETY X

ACTION RECOMMENDED: Procedural or automatic controls should be implemented to prevent attempts to translate before separation is completely effected.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				Marginal

171

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED ______

HAZARD ANALYSIS

PAGE ____ OF ____

DATE ______

REV ______

END ITEM ESS/Prop Tank/CIS — SUBSYSTEM Avionics	SUBSYSTEM IDENT NO. 1
OPERATION/PHASE Orbital-Undock user from ESS/Prop Tank	OP. IDENT. NO. C
HAZARD GROUP Impact	HAZARD GRP. CODE 9
REFERENCES FMEA 6.1B	AUTHORITY

HAZARD DESCRIPTION/ EFFECTS Inadvertent activation of ESS thrusters prior to attainment of adequate separation distance could cause the ESS or propellant tank to impact the CIS. The area of impact is dependent upon the thruster banks energized and length of time of activation. Any thruster operation except those providing separation translation or roll, could cause impact. The inadvertent activation could be from human error in ground control or malfunction within the computer.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			Critical

COPIES TO: STRUCTURAL ____ MECHANICAL ____ MATERIALS ____ GSE ____ OTHER ____

AVIONICS ____ PROPULSION ____ VEHICLE SUPPORT ____ FACILITIES ____ PAYLOAD ____ SYS SAFETY X

ACTION RECOMMENDED: To prevent human error during translation maneuvers the operator should be trained and guided by procedural controls. Alternate computer systems should be provided as back-up in case the primary system fails.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				Marginal

172

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED

HAZARD ANALYSIS

PAGE ____ OF ____

DATE ____

REV ____

END ITEM ESS/Prop Tank/CIS	SUBSYSTEM Avionics	SUBSYSTEM IDENT NO. 1
OPERATION/PHASE Orbital-Undock user from ESS/Prop Tank		OP. IDENT. NO. C
HAZARD GROUP Impact		HAZARD GRP. CODE 9
REFERENCES FMEA 6.1B		AUTHORITY

HAZARD DESCRIPTION/ EFFECTS Human error in commanding improper thruster operation on the CIS could impact the ESS/Prop Tank. This could be caused by disorientation of the ground crew if certain docking aids on the ESS/Prop Tank were used for reference purposes, while control of the CIS should have been from a CIS reference. The effect is essentially a potential crossed control.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			Critical

COPIES TO: STRUCTURAL ____ MECHANICAL ____ MATERIALS ____ GSE ____ OTHER ____

AVIONICS ____ PROPULSION ____ VEHICLE SUPPORT ____ FACILITIES ____ PAYLOAD ____ SYS SAFETY X

ACTION RECOMMENDED: To Minimize human error during critical undocking maneuvers operators should be trained to select the proper reference data. Procedural controls should be implemented to prevent reaction on confusing data until the confusion can be resolved.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				Marginal

173

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED ______

HAZARD ANALYSIS

PAGE ____ OF ____

DATE ______

REV ______

END ITEM ESS/Prop Tank	SUBSYSTEM Avionics	SUBSYSTEM IDENT NO. 1
OPERATION/PHASE De-Orbit - Perform ESS deorbit to earth impact		OP. IDENT. NO. D
HAZARD GROUP Impact		HAZARD GRP. CODE 9
REFERENCES FMEA 6.2B		AUTHORITY

HAZARD DESCRIPTION/ EFFECTS Failure of the avionics system (power or computer) or failure of thrusters to activate for purposes of deorbit orientation, could cause the ESS to impact in an area outside of the planned footprint. This is caused by inability to control attitude during deorbit burn of the OMS engine. Major hazard would be impact in populated area.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			Catastrophic

COPIES TO: STRUCTURAL ____ MECHANICAL ____ MATERIALS ____ GSE ____ OTHER ____

AVIONICS ____ PROPULSION ____ VEHICLE SUPPORT ____ FACILITIES ____ PAYLOAD ____ SYS SAFETY X

ACTION RECOMMENDED: The de-orbit burn of the ESS should not be initiated before the vehicle is verified to be properly oriented to splashdown in the chosen footprint.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				Critical

174

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED

HAZARD ANALYSIS

PAGE ____ OF ____
DATE ____
REV ____

END ITEM ESS/Prop Tank	SUBSYSTEM Propulsion	SUBSYSTEM IDENT NO. 2
OPERATION/PHASE Deorbit - Perform ESS deorbit to earth impact		OP. IDENT. NO. D
HAZARD GROUP Loss of thrust/impact		HAZARD GRP. CODE 7,9
REFERENCES FMEA 6.2B		AUTHORITY

HAZARD DESCRIPTION/ EFFECTS Failure of the turbopump gas generator propellant shutoff valves (O_2 & H_2) to close would have caused excessive leakage during orbital operations. This could cause eventual loss of propellants for the deorbit function. This failure would cause loss of OMS engine thrust and also loss of thruster capability. This would cause reentry by orbit decay which through random impact could endanger populated areas.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			Catastrophic

COPIES TO: STRUCTURAL ____ MECHANICAL ____ MATERIALS ____ GSE ____ OTHER ____

AVIONICS ____ PROPULSION ____ VEHICLE SUPPORT ____ FACILITIES ____ PAYLOAD ____ SYS SAFETY X

ACTION RECOMMENDED: The GG propellant shutoff valves should have alternates to shut off propellant flow in the event that the primary valves fail.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				Critical

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED ____

HAZARD ANALYSIS

PAGE ____ OF ____

DATE ____

REV ____

END ITEM ESS/Prop Tank	SUBSYSTEM Mechanical	SUBSYSTEM IDENT NO. 4
OPERATION/PHASE Deorbit - Perform deorbit to earth impact		OP. IDENT. NO. D
HAZARD GROUP Impact		HAZARD GRP. CODE 9
REFERENCES FMEA 6.2B		AUTHORITY

HAZARD DESCRIPTION/ EFFECTS Failure of retroburn due to delays in valve actuation or execution of command by ground control could place the impact of the ESS/tank in an area outside the planned footprint, causing impact in populated areas.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			Catastrophic

COPIES TO: STRUCTURAL ____ MECHANICAL ____ MATERIALS ____ GSE ____ OTHER ____

AVIONICS ____ PROPULSION ____ VEHICLE SUPPORT ____ FACILITIES ____ PAYLOAD ____ SYS SAFETY X

ACTION RECOMMENDED: The initiation and duration of retro burn should be provided as an automatic function to back up manual control.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				Critical

176

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED

HAZARD ANALYSIS

PAGE ___ OF ___
DATE ___
REV ___

END ITEM ESS/Prop Tank	SUBSYSTEM Propellant	SUBSYSTEM IDENT NO. 11
OPERATION/PHASE Deorbit-Perform ESS deorbit to earth impact		OP. IDENT. NO. D
HAZARD GROUP Loss of thrust/impact		HAZARD GRP. CODE 7, 9
REFERENCES FMEA 6.2B		AUTHORITY

HAZARD DESCRIPTION/ EFFECTS Failure to hold attitude until engine retro burn cutoff could cause disorientation of the ESS upon reentry. This would cause undesired aerodynamic instability which may cause breakup above desired altitudes which may cause impact outside the footprint.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			Critical

COPIES TO: STRUCTURAL ___ MECHANICAL ___ MATERIALS ___ GSE ___ OTHER ___

AVIONICS ___ PROPULSION ___ VEHICLE SUPPORT ___ FACILITIES ___ PAYLOAD ___ SYS SAFETY X

ACTION RECOMMENDED: The attitude control system should have secondary capability in critical areas to provide the correct attitude in the event the primary means fails.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				Marginal

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED ______

HAZARD ANALYSIS

PAGE ____ OF ____
DATE ______
REV ______

END ITEM ESS/Prop Tank	SUBSYSTEM Avionics	SUBSYSTEM IDENT NO. 1
OPERATION/PHASE Deorbit - Perform ESS deorbit to earth impact		OP. IDENT. NO. D
HAZARD GROUP Reduced integrity of structure or equipment		HAZARD GRP. CODE 2
REFERENCES FMEA 6.2.B		AUTHORITY

HAZARD DESCRIPTION/ EFFECTS There is a possibility that the propellant tank to ESS separation device may be activated during reentry. This separation may cause tank instability which causes impact of exploded fragments over a wide area. This assumes the tankage would burn through and explode.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			Critical

COPIES TO: STRUCTURAL ____ MECHANICAL ____ MATERIALS ____ GSE ____ OTHER ____

AVIONICS ____ PROPULSION ____ VEHICLE SUPPORT ____ FACILITIES ____ PAYLOAD ____ SYS SAFETY X

ACTION RECOMMENDED: The footprint chosen should be large enough to encompass all fragments of the ESS/Tank.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				Marginal

CONTRACT NAS8-27692

LOCATION/SITE INVOLVED ______

HAZARD ANALYSIS

PAGE ____ OF ____
DATE ______
REV ______

END ITEM ESS/Prop Tank	SUBSYSTEM Structural	SUBSYSTEM IDENT NO. 5
OPERATION/PHASE Deorbit-Perform ESS deorbit to earth impact		OP. IDENT. NO. D
HAZARD GROUP Fire/explosion/implosion		HAZARD GRP. CODE 1
REFERENCES FMEA 6.2B		AUTHORITY

HAZARD DESCRIPTION/ EFFECTS In the event the tanks on the ESS or propellant tankage have been vented to vacuum while in orbit, it could reasonably be expected that the tanks would implode and explode upon entry into the earth's atmosphere. This is caused by inability to equalize the pressures across the tank walls rapidly.

ORIGINATOR	GROUP	EXT.	HAZARD CLASS
			Critical

COPIES TO: STRUCTURAL ____ MECHANICAL ____ MATERIALS ____ GSE ____ OTHER ____

AVIONICS ____ PROPULSION ____ VEHICLE SUPPORT ____ FACILITIES ____ PAYLOAD ____ SYS SAFETY X

ACTION RECOMMENDED:

The footprint chosen should be large enough to encompass all fragments of the ESS in the event it explodes.

REQUIRED PRIOR TO	RECOMMENDED BY	GROUP	EXT.	HAZARD REDUCED TO
				Marginal

APPENDIX D

PREVENTIVE MEASURES

In the development of preventive measures, the objective was to reduce catastrophic and critical hazards to the category of at least marginal and preferably negligible. As each hazard was identified on the hazard analysis sheet (Figure D-1), the steps to be taken to reduce the hazard to an acceptable level were detailed in the "Action Recommended" blank. This "Action Recommended" then becomes the preventive measures.

This section opens with a discussion of the hazard reduction precedence sequence and how it was used in deriving preventive measures.

In paragraph 2 preventive measures are derived for the safety critical operations performed in space during propellant logistics operations.

Paragraph 3 establishes the need for a manned monitor of orbital propellant logistics functions, discusses some of the data the monitor must have available to evaluate the progress of events and determine when manned over-ride and control become necessary.

Paragraph 4 enumerates the thirty-three residual hazards of propellant logistics operations, discusses the factors contributing to their being classed as residuals and points out that they deserve continued emphasis until they are reduced.

1. Hazard Reduction Precedence Sequence

   The study ground rules stipulated that the Hazard Reduction Precedence sequence of SPD-1A would be used in the reduction of hazard potential.

   This sequence requires that the major effort throughout a program must be in the <u>design</u> process. Every effort must be made to prevent the occurrence of the hazard by designing all systems, subsystems and components such that the identified hazard cannot occur.

   If the hazard cannot be designed out of the system and it is still possible to occur, then <u>safety devices</u> should be incorporated to counter the effects of the hazard.

   When a hazard cannot be designed out of the system and safety devices will not eliminate the hazard effects, then <u>warning devices</u> will be incorporated in the system to warn the system operators of the occurrence of the hazard.

   If none of the above preventive measures will prevent the occurrence of the hazard, then <u>procedures</u> shall be developed to operate the systems in such a manner that the hazard cannot happen.

In the event that none of the above will reduce the hazard potential to an acceptable level, and residual hazards remain, program management shall be notified of the presence of the unresolved hazard. Management then has the option of modifying the program direction to choose alternate, less hazardous solutions, developing new technology to counter the hazard, or, as a least desirable choice, to accept the risk of the hazard.

2. Preventive Measures for In-Space Propellant Logistics Safety Critical Operations

As a part of the safety analysis, preventive measures were developed for the safety critical operations that would be performed during deployment, docking, transfer and retrieval. Table 2.1-1 is used as the outline for the concepts and operations in the subsequent discussion.

The rows were identified "A" through "G" and the columns were numbered 1 through 4. Identifier A-2-2 would be the performance of "Remote Hard Dock CIS to LSF," using the baseline concept. The hazards attendant to the execution of this operation were listed and on the same horizontal line the preventive measures were listed that should be performed to reduce the hazard.

Preceding the preventive measure a letter has been included in parentheses. This letter indicates which step in the hazard reduction precedence sequence has been selected as the preferred method of reducing the hazard to an acceptable level. (D) indicates that design is the preferred method of hazard reduction, (S) indicates that design effort will not reduce the hazard and safety devices should be incorporated, and (P) indicates that neither design nor safety devices will reduce the hazard to an acceptable level and that special procedures must be employed.

a. A-1-1 Concept-Baseline, Operation-Deployment (Propellant Tank Module Deployed by Manipulators from Cargo Bay)

During this operation the shuttle orbiter has delivered a propellant module to orbital altitude. The orbiting propellant depot has been assembled in orbit and the shuttle is station keeping, with cargo bay doors open, ready to deliver a propellant module. Deployment will consist of those steps to be taken to sever the interface of the module and shuttle and remove the module from the cargo bay by the use of manipulators.

Hazard	Preventive Measure
(1) Tank rupture	(S) Pressure relieving devices
(2) Index probes will not release prior to deployment	(D) Redundant release mechanism
(3) Mass leakage into cargo bay	(P) Visually inspect cargo bay prior to deorbit
	(D) Eliminate confined compartments
(4) Propulsive venting, leaking	(D) Provide RCS capability to overcome any vehicle instability
	(D) Slosh dampeners
(5) Indexing probes fail to release from cargo bay interface	(D) Provide redundant release mechanisms
(6) QD fails to seat on release	(D) Provide redundant valves
(7) Visual restrictions by "ice" from leaks	(D) Provide retractable shields for visual aids
(8) Propellant tank penetration by manipulators during removal from cargo bay	(P) Crew Training
	(P) Procedures development
	(P) Prior operational checkout of manipulators
(9) Meteoroid penetration	(D) Provide meteoroid shield
(10) Intermittent RCS operation	(D) Redundant RCS controls
	(D) Provide RCS accumulators to insure propellants available
	(P) Verify availability of RCS propellant
(11) Jerky operation of manipulators	See A-1-1(8) above
(12) Impact due to loss of control of manipulators	(D) Redundant manipulator controls
	See A-1-1(8) above.

Hazard	Preventive Measure
(13) Tank vent fails in open position	(D) Redundant means of closing vents
	See A-1-1(4) above

b. A-2-1 Concept-Baseline, Operation-Docking (Shuttle Soft Docks Propellant Tank Module to LSF)

During this operation the shuttle is station keeping with the LSF, with the propellant module on the extended manipulator arms. The manipulator arms will be used to soft dock the module and rigidize the module to the LSF. Then the orbiter translates away from the LSF/module combination. Included in this operation is the requirement to maintain vehicle stability from sloshing, venting or other unstabilizing influences while the element is attached to the manipulator arms.

Hazard	Preventive Measure
(1) Excessive velocity of soft dock	(D) Limit energy that can be imparted by manipulators
	(P) Crew training
	(P) Procedures development
(2) Excessive angular deviation causing impact	See A-2-1(1) above
(3) Impact by space debris	(P) Time launch to miss debris detectable by ground radar
	(P) Impact by space debris for long orbital stay time is a residual hazard
(4) Loss of RCS	See A-1-1(10) above
(5) Loss of rigidization	(D)(P) RCS system of passive element should be de-energized or tied in with active element as soon as rigidization is complete
	(D) Provide redundant capture latches
(6) Tank vent valve fails in open position	See A-1-1(13) above

Hazard	Preventive Measure
(7) Attempt to capture unstable vehicle	(P) Procedural controls should be implemented to prevent capture of unstable vehicles

c. A-2-2 Concept-Baseline, Operation-Docking (Remote Hard Dock CIS to LSF)

During this operation the CIS/RNS will dock, remote from any manned assistance, and thus automatically. Of further significance is the large mass of both vehicles. Additional consideration would involve momentum and the possible excursion of residual CIS/RNS propellants from one end of the tank to the other during the docking impact. The passive vehicle is the LSF; the active vehicle is the CIS/RNS.

Hazard	Preventive Measure
(1) Excessive closing velocity causes impact damage	(D) Repetitive operations should be automated with automatic withhold for excessive velocity and angular deviation
	(D) Docking controls should have backup
	See A-1-1(10) above
(2) Excessive angular deviation causes impact damage	See A-2-1(1) above
(3) Attempts to dock unstable vehicles causes impact damage	(D) Provide automatic withhold if target cannot be acquired within design limitations

See the following items for additional docking preventive measures: A-1-1(1), A-1-1(4), A-1-1(9), A-1-1(10), A-2-1(2), and A-2-1(5).

d. A-3-1 Concept-Baseline, Operation-Transfer (Rotational Acceleration of LSF for Propellant Settling - CIS/RNS - Orbiter Not Attached)

During this operation the LSF and CIS/RNS have docked, the interface is rigidized and pre-transfer operations have been completed. Rotational acceleration will be initiated by firing the RCS of the coupled elements to achieve the necessary rotational speed to settle the propellants.

Hazard	Preventive Measure
(1) Erratic fuel flow to Gas Generator causes unstable output	(D) Provide GG accumulators to insure propellants available
	(D) Provide strainers or filters to prevent contamination from blocking orifices
	(D) Provide redundant fuel controls
	(D) Provide slosh dampeners to reduce vapor pull-through
	(D) Provide anti-vortex devices to reduce vapor pull-through
(2) Instability in Heat Exchanger	(P) Proof test Heat Exchanger
	(S) Provide GG over-temperature or over-pressure and instability correction
	See A-3-1(1) above
(3) Structural failure due to vehicle instability	(D)(P) See A-2-1(5)
	(D) Slosh dampeners
	(D) RCS should correct instability of vehicles under any dynamic conditions
(4) Propellant leakage causes explosive mixture	(D) Eliminate confined compartments
(5) Failure of relief valve in closed position causes burst disc rupture	(D) Redundant relief valve
	(D) See A-1-1(4) above
(6) Thermal shock because of rapid chilldown	(D) Automatic withhold if lines/ tanks not down to temperature
(7) Dynamic loading of joints and interfaces	(D) Provide rigidization fixture that will resist vehicle instability
	(D)(P) See A-3-1(3) above

Hazard	Preventive Measure
(8) Unable to shutdown and despin due to vehicle instability	(D)(P) See A-3-1(3) (D)(P) See A-1-1(10)
(9) Wobble during fluid transfer	(D)(P) See A-3-1(3)

See the following items for additional transfer preventive measures: A-1-1(4), A-1-1(7), and A-1-1(9).

e. A-4-1 Concept-Baseline, Operation-Retrieval (Propellant Tank Retrieval Placement in Cargo Bay and Deorbit of Orbiter)

During this operation the orbiter will station keep with the stable LSF, remove the empty module from the LSF, translate away, position the module in the cargo bay, make necessary verification tests, close the doors and deorbit. The stability of the module while on the manipulator arms and the influence of residual propellants is of concern.

Hazard	Preventive Measure
(1) Propellant leakage causes "ice" on module or cargo bay walls leading to fire/ explosion	(P) Conduct visual inspection of cargo bay and module (P) Defer re-entry until "ice" has sublimed
(2) Negative pressure in module tanks causes implosion/fire/ explosion	(P) Do not deorbit any tank that cannot be verified to be within structural limits of atmospheric pressure
(3) Venting into cargo bay during re-entry	(D) Provide closed venting system from module through shuttle to ambient (P) Leak check shuttle/module vent interface prior to de-orbit
(4) Improper stowing of module leads to shifting and tank rupture	(D) Each shuttle cargo should be provided with rigid tie-down (P) Verify tie-down rigidized prior to deorbit
(5) Failure of indexing probes to release prior to undocking	(D) See A-1-1(5)

Hazard	Preventive Measure
(6) Any conditions of impact which cause penetration of module propellant system	(D)(P) Same as conditions developed under deployment operations

See the following items for additional retrieval preventive measures: A-1-1(4), A-1-1(6), A-1-1(7), and A-2-1(1).

f. B-2-1 Concept-Orbiter/Tug/LSF, Operation-Docking (Remote Hard Dock Tug/Module to LSF)

The new elements that have been added in this operation are the remote automatic docking of a small mass (tug) to a large mass (LSF).

Hazard	Preventive Measure
(1) Docking impact, small mass to large mass	(D) Docking mechanism must be capable of absorbing momentum of docking between large and small vehicles to minimize dynamic instability in either vehicle

See A-2-1 and A-2-2 for other docking preventive measures.

g. C-2-1 Concept-Booster/ESS/Large Propellant Tank, Operation-Remote Hard Dock Tug/Modulate LSF (Remote Hard Dock of Large Propellant Tank with CIS/RNS)

During this operation the added operation is the remote, automatic docking of a large tank with the CIS/RNS after having been boosted by the ESS.

See B-2-1 for docking preventive measures.

h. D-3-1 Concept-Orbiter to Orbiter Operation - Transfer (Flex Lines Used by Attaching at QD with Use of Manipulators)

During this operation the additional elements that have been added are the station keeping of two orbiters and the use of manipulators to hook up flex lines in preparation for propellant transfer.

Hazard	Preventive Measures
(1) TPI damaged on removal or replacement by manipulators leading to fire/explosion on shuttle re-entry	(P) See A-1-1(8)
	(P) Perform visual inspection of TPI after replacement
	(P) Delay re-entry until TPI is repaired/replaced
(2) QD leaks on hook-up	(D)(P) See A-1-1(7)
	(D) Eliminate confined compartments
(3) QD leaks on release	(D) Provide back-up valve
(4) QD hangs up on attempting to release	(D) Provide back-up release mechanism
(5) Long flex line becomes fouled when paid out and ruptures line	(D) Provide reels for flex line or other devices to minimize fouling
(6) Flex line ruptures and whips, damaging orbiter/orbiters	(D) Provide isolation valve in supplier line
	(D) Provide supports at intervals on manipulator arm
(7) Freezing of propellants in long (70') flex lines	(D) Provide heaters on flex lines

See A-1-1 for other deployment preventive measures.
See A-2-1 and A-2-2 for other docking preventive measures.
See A-3-1 for other transfer preventive measures.
See A-4-1 for other retrieval preventive measures.

i. D-3-2 Concept-Orbiter to Orbiter, Operation-Transfer (Positive Displacement Method used for Propellant Transfer)

The added element during this operation is the use of positive expulsion, bladders or bellows, to transfer propellants.

Hazard	Preventive Measure
(1) Rupture at diaphragm or bellows by excessive pressure	(D) Provide pressure relieving devices

Hazard	Preventive Measure
(2) Leakage of both propellants into common pressurizing gas source, leading to fire/explosion	(D) Provide redundant isolation between common source and propellant cavities

See D-3-1 for other preventive measures dealing with transfer by flex lines.

j. E-1-1 Concept-Orbiter to Tug, Operation-Deployment (Propellant Tank Module Deployed by Rotational Deployment Mechanism)

During this operation the introduction of rotational devices was made to deploy a propellant module out of the cargo bay of the shuttle. An item of concern is the lateral stability of the module while being rotated out of the cargo bay.

Hazard	Preventive Measure
(1) Rotational mechanism jams with module partially deployed	(D) Provide redundancy in rotational mechanism
	(D) Provide means to release drive mechanism and complete deployment by manipulators

See A-1-1 for additional deployment preventive measures.

k. E-3-1 Concept-Orbiter to Tug, Operation-Transfer (Rotational Acceleration for Propellant Settling with Orbiter Attached)

For this operation the orbiter remains attached to serve as a counterweight while transferring propellants from a module to a tug. Of significance is the fact that the orbiter crew will remain relatively inactive for long periods (ten-hour transfer time), and will be subject to any instability introduced by the assembly that might be detrimental to human performance.

Hazard	Preventive Measure
(1) Because of failure on tug or method of operation of tug the man rating of the orbiter is compromised	(D)(P) No attached element will degrade the man rating of the manned element either by design or operation.
(2) Long period of rotation degrades man's reaction	(P) Procedures will be developed to insure rest and food to retain man's capability

Hazard	Preventive Measure
(3) Control failure will introduce excessive rotational speeds and degrade man's control capability	(D) Provide redundancy in critical RCS controls

See A-3-1 for other rotational acceleration preventive measures.

l. E-3-2 Concept-Orbiter to Tug, Operation-Transfer (Linear Acceleration for Propellant Settling with Orbiter Attached)

Linear acceleration of the orbiter/module/tug combination is introduced in this combination. Again the orbiter crew will be relatively inactive for ten hours and will be subject to any instability introduced by the assembly that might be detrimental to human performance.

Hazard	Preventive Measure
(1) RCS failure because of long-term usage	(D) To provide the continuous thrust required for linear acceleration consideration should be given in the design process for low-thrust engines other than RCS, since the RCS may not have continuous operation as a design requirement

See A-3-1 for other transfer preventive measures.

m. F-2-1 Concept-Orbiter to CIS/RNS, Operation-Docking (Orbiter Hard Docks Propellant Tank Module to CIS/RNS)

During this operation the orbiter will be required to station keep with a modular CIS, remove a module from the cargo bay and soft-dock it to the CIS, rigidize the module and translate away.

Hazard	Preventive Measure
(1) Compromise of orbiter man rating	(D)(P) See E-3-1(1)

See A-2-2 and B-2-1 for other docking preventive measures.

n. F-3-1 Concept-Orbiter to CIS/RNS, Operation-Transfer (Linear Acceleration for CIS/RNS Tank Module Propellant Settling with Orbiter Not Attached)

In this operation a large vehicle (CIS/RNS) and a small vehicle (module) will be linearly accelerated for the propellant transfer (ten hours) with continuous thrusting from small engines, in an unmanned, automatic mode.

See E-3-2 for linear transfer preventive measures.

o. F-3-2 Concept-Orbiter to CIS/RNS, Operation-Transfer (Capillary Fluid Control for CIS/RNS Tank Module Propellant Transfer)

During this operation the concept of propellant settling by the use of capillary devices is introduced.

Hazard	Preventive Measure
(1) Structural failure of capillary devices	(D) The design process should provide structural integrity of screens while fluid is sloshing or when struck by solid particles and resist buckling when clogged by contaminating solid particles
(2) Premature wetting of self wicking screen reduced capability	(D) The design process should minimize premature wetting by baffles
	(D) Excessive flow should be eliminated to prevent geysering
(3) Heat leaks reduce effectivity due to propellant boiling	(D) Prior to propellant transfer a visual inspection should be made of integrity of insulation

See A-3-1 and E-3-1 for other transfer preventive measures.

p. G-1-1 Concept-Orbiter to Modular CIS, Operation-Deployment (Propellant Tank Module Deployed by Rotational and Manipulator Mechanisms)

This mode of operation introduces the deployment of numerous loaded propellant modules to be used in building-block fashion to make up a full CIS propellant load

See A-1-1 for manipulator deployment preventive measures.
See E-1-1 for rotational deployment preventive measures.

3. Monitoring Devices

It is visualized that a concept as complex as providing propellant for the space program through 1990 could, conceivably, be made fully automatic with no intervention by man being required. At this time the prime delivery element is the shuttle orbiter which is largely under manual control. Other manual operations, such as space maintenance, have been considered to be, if not an integral factor in propellant logistics operations, at least an option to be used, if necessary.

When manual operations are integrated into any automatic operation it imposes the requirement of providing another manual operation, that of monitoring the progress of events. Even if no manual operations were contemplated in propellant logistics operations, it is visualized that at least mission completion would be a necessary function to be monitored. Furthermore, even fully automatic operations, regardless of the level of redundancy can fail and trouble shooting data is necessary for human intervention, analysis and corrective action.

In establishing the necessity for a monitor to be aware of the progress of orbital events, a manned ground station becomes necessary, since a manned element (orbiter) is not always present. When an orbiter is present in the vicinity of orbital propellant logistics operation, however, the crew should be provided with the status of such operations as to be capable of assuming control since they are closer to the operation in progress. Contradictory commands should be eliminated by procedures when two manned elements have control capability and ground control should defer to orbital control when orbital control is possible.

To acquire the necessary data to permit the monitor to be able to be effective, the design process should consider the provision of monitoring devices to include the following:

Electrical power - Voltage and current levels of electrical power and whether operating on primary or reserve supplies.

Pneumatic supply - The pressure level of the pneumatic supply will be needed to evaluate the ability to complete subsequent missions.

Valve position indicators - The open or closed indication of valves that are operated during a planned event.

Propellant tank pressure and temperature - A readout of the propellant tank pressure and temperature will be required to evaluate propellant usage and leakage, at a minimum.

Propellant gauging - The quantity of propellants in the supplier and user tanks should be available.

Operating cycles - A means of recording the number of operating cycles of limited life components.

Leak check - Provide a means to verify that all possible sources are free of leaks.

Line interconnect fixture rigidization - A method of verifying that the interface between elements has been securely mated.

Docking latches - The captured or released status of docking latches should be available.

Redundant system status - The operational level, whether on primary or reserve, should be available.

Hazardous Gas Concentration - Flammable gas detectors should be provided for all restricted compartments (such as cargo bay) for ground operations.

Fire Detectors - Fire detectors should be provided for all restricted compartments (such as cargo bay) for ground operations.

Life support system operational level - For manned operations the operational levels of LSS fluids, and the presence of toxic gases should be provided to the crew being supplied.

Space debris warning - Since impact by space debris is a residual hazard, collision warning devices should be given consideration.

The above listed monitoring devices would provide the Control Monitor with the operational status of orbital operations. Intervention at critical stages implies the communication of data during these critical stages. Further study would be necessary to fully define the operational capability of the communications systems.

4. Residual Hazards

In the application of the Hazard Reduction Precedence Sequence to reduce hazards design effort, safety devices, warning devices and special procedures are used. If the application of these measures does not reduce the hazard level to an acceptable degree, then these hazards are residual ones. For the purposes of this study, only those hazards that were categorized as catastrophic or critical were considered. For the purposes of this study then, those hazards that remain at the level of catastrophic or critical after the application of the recommended preventive measures are residual hazards.

The residual hazards are identified on the Hazard Analysis sheet (Appendix C) in the "Hazard reduced to" blank. If the hazard remains listed as catastrophic or critical in this blank, it is a residual one.

For the convenience of the reader, the orbital operations residual hazards are discussed below:

H/A #14, 102, 153 - Meteoroid Impact - The impact by hyper velocity meteoroids that could cause loff of life or mission and cannot be avoided.

H/A #31 - EVA Operations - EVA remains a safety critical operation because of the lack of redundancy of LSS.

H/A #47, 87 - Propellant Quantity - The lack of knowledge of the quantity of propellants for mission completion, RCS action and orbiter landing weight could result in loss of mission, orbiter or crew and remains a residual hazard.

H/A #52, 118, 120, 121, 161 - Disturbances - Overall vehicle dynamics is critical to the success of propellant logistics operations and any factor that could lead to the loss of stability is a residual hazard.

H/A #68, 73 - Propellant Venting into Cargo Bay - The accumulation of 4% hydrogen in the cargo bay would be catastrophic to the orbiter and crew. By the use of the recommended preventive measures the hazard remained critical.

H/A #74 - Propellant Leakage into Cargo Bay - The accumulation of 4% hydrogen could lead to the loss of the orbiter and crew. Undetected leakage from any cause is a residual hazard.

H/A #76 - Hard Landing - The landing weight at the shuttle cargo is limited to 40K lbs. The requirement to achieve this weight as applied to propellant logistics elements is critical to the orbiter and crew.

H/A #80, 133 - Negative Pressure/Mass Spill - Tank implosion would be likely to introduce combustible gases into the cargo bay and be catastrophic to the orbiter and crew. The application of the preventive measures would reduce this hazard to critical.

H/A #96, 99, 107 - Docking Hazards - The control of the orbiter is largely manual and docking and separation maneuvers remain a critical operation.

H/A #97 - Docking Between Unstable Vehicles - Errors of judgement during a manual docking maneuver could introduce critical hazards when either or both of the vehicles are unstable.

H/A #101 - Systems' Failure During Rendezvous - A failure in any one of the several systems that are involved could introduce critical hazards.

H/A #102 - Space Debris - The impact of space debris remains as a catastrophic hazard.

H/A #115 - Reduction of Vision - The provision of retractable shields to reduce the formation of "ice" on visual aids reduces the hazard from catastrophic to critical. The finite reaction time for the operator to actuate the controls still leaves the chance that some clouding would occur and results in a critical hazard.

H/A #126 - Failure of Release Mechanisms - Provision of a means to notify operator that release mechanisms are unlocked and free does not prevent human error from attempting to translate with one or more latches still engaged and hazard remains critical.

H/A #131, 132 - Loss of Attitude Control - The loss of attitude control from any source remains a critical hazard.

H/A #147 - Loss of Thrust on ESS - The fact that a single order failure exists in the ESS (S-II) vent valves is known and accepted for the S-II vehicle. It must remain a critical hazard for the ESS, however,

H/A #148 - Reduced Integrity of Pressurization System - The fact that both vent valves are commanded to low mode with a single electrical signal is accepted on the S-II Program. It must remain a critical hazard for the ESS, however.

H/A #160, 174, 175, 176 - ESS Footprint - The deorbit of an ESS with a fully loaded propellant module could have catastrophic results in populated areas. The choice of the footprint and the achievement of this footprint remains a critical hazard.

The above listed 33 residual hazards have been identified during the course of the hazard analysis. The possible preventive measures that could be applied did not reduce the hazard potential to an acceptable level. Continued effort should be applied to the reduction of these hazards. As a propellant logistics is defined and implemented, new technology that becomes available in the intervening time should be applied to hazard reduction.

APPENDIX E

SAFETY CRITERIA

System Safety criteria was developed at the initiation of the study for use in establishing the proper perspective for safety requirements. This criteria was followed by safety criteria for use in slush utilization considerations.

Propellant transfer alternatives were considered in the ISPLS study, and the effort was supported with System Safety criteria for application to the alternatives considered.

<u>System Safety Criteria for ISPLS Study</u>

1. Propellant logistic elements which are designed for automatic remote operation shall include provisions for space crew operations support in an activation, emergency or maintenance operational mode.

2. Orbital Propellant Logistics System elements shall provide a habitable environment in all areas designated for frequent onboard maintenance activities.

3. Internal areas of Logistics System elements which may require unscheduled maintenance activities shall be accessible for suited IVA.

4. No in-orbit maintenance shall be conducted inside of orbiting propellant storage tankage.

5. Where the shuttle orbiter is hard docked to a propellant depot element, the stability of the entire configuration shall be such as to preclude disturbances which are detrimental to the orbiter crew members during preparations for propellant transfer operations.

6. For those malfunctions and/or hazards which may result in time-critical emergencies, provisions shall be made for automatic switching to a safe mode of operation and for alerting and warning personnel of the malfunction within the system.

7. Any operational mode of logistic propellant elements in which propellant tankage is opened to space vacuum environment shall incorporate a provision for tank pressurization when the tank is to be returned to earth in the shuttle orbiter.

8. Provisions shall be incorporated in all orbital propellant logistic elements to measure the quantity of propellants transferred into or removed from storage elements and the number of pressure cycles imposed on the pressurized tank.

9. Any propellant module damaged to the extent that leakage of propellants could be expected to occur in the shuttle orbiter cargo bay upon re-entry, shall not be returned to earth by the orbiter.

10. EVA shall be conducted either by using the "buddy" system or within visual range of a suited crewman acting as a safety backup.

11. Propellant modules which have sustained meteoroid impact but have self sealed due to ice plus formation shall not be returned to earth in the shuttle cargo bay unless repairs can be effected prior to placement in the shuttle orbiter cargo bay.

12. Hazardous operations during initial system checkout in space shall be accomplished from a remote location prior to exposure of operating or maintenance crews.

13. Interfaces which involve mating by indexing and rigidization between logistic elements for the purpose of propellant transfer, shall be capable of separating under conditions where the rigidizing fixture fails to release under normal separation conditions.

14. Propellant logistic elements shall preclude the possibility of inadvertent activation of critical systems through design considerations and use of protective devices.

15. Capability shall be provided for performing critical functions at a nominal level with any single component failed or with any portion of a subsystem inactive for maintenance.

16. The Propellant Logistic System operations shall be conducted to preplanned procedures. Safety Critical procedures shall be approved by System Safety Engineering, Engineering and Flight Operations.

17. Vent systems design shall preclude the buildup of ice in a manner that could restrict the flow of vented fluids.

18. At least two paths of emergency egress shall be provided in any passage, compartment or propellant logistic element that involves the human element in space.

19. Ground operations involving the transfer of Slush H_2, LH_2 or GH_2 shall be considered Safety Critical. The requirements for facilities design of emergency off-loading and venting systems shall take precedence in any cost trade.

20. The loss of the stabilization system in an "in-space" propellant logistic element shall be cause for mandatory and automatic withholding of docking privilege for the purpose of propellant transfer.

21. The propellant modules or other propellant containers carried in the shuttle orbiter cargo bay shall be configured such as to preclude venting into the cargo bay.

22. Handling devices for IVA transfer of propellant modules shall preclude the hazard of impact damage to the module through design of restraint provisions limiting movement within the cleared access corridors.

23. Line segments shall be capable of isolation and provided with drain and purge capability for maintenance functions. Segments of lines which are locked up such as to entrap fluids shall incorporate pressure relieving provisions to prevent line rupture.

24. Where artificial "G" is employed by rotational means, redundant means for stopping the rotational movement shall be provided.

25. Crew operations requiring EVA for maintenance or emergency repair shall be supported in the propellant logistic element design with handrails or other provisions for securing a firm position during the operation.

26. Traffic patterns to a large storage facility (LSF) shall be preplanned and controlled. No approach or docking shall be made outside the radiation protection cone, when the RNS is docked to the LSF.

27. Each propellant logistic element shall provide a compatible configured means for grounding the interface and element with docking elements to equalize the electrical potential of the configuration prior to transfer of propellants.

System Safety Criteria for Hydrogen Slush Utilization

1. Consider the quantity distance requirements for explosive overpressures in computing the line distances for slush transfer between the facility and pad.

2. Emergency off load requirements of slush via transfer lines or the off loading of the propellant module should be a positive consideration in all cost assessments (facilities, operations) for the cases of emergencies and pad abort operations.

3. Where the propellant module is utilized with approximately 100% of the volume loaded with slush, consideration of possible two-phase flow in the pad vent system should be programmed in slush utilization considerations.

4. Any transfer operation involving slush shall be capable of insuring the flow through the transfer lines exceeds the critical velocity at all times.

5. In the ground loading of propellant modules, the facility must be capable of measurement of the solid fraction of slush propellants entering the tankage to assure sufficient ullage volume to compensate for increased volume due to heat leaks.

6. Since slush has the potential for destroying the functional capability of capillary screens, the effect of this hazard shall be assessed against the propellant leveling devices replacing the screens.

7. Consider the effect on internal tank components such as screens, baffles, sensors, etc., for the case of slug flow discharging into the propellant tank as a result of heat leaks during flow interruption.

8. Consider flow interruption as a possibility in slush transfer operations by pump or pressure loss.

9. Consider the condition which could occur if purge pressure to the HPI insulation is lost while the propellant module is installed in the orbiter cargo bay, and the emergency equipment necessary for recovery.

Propellant Transfer Options Safety Criteria

The selection of transfer alternatives being considered by Project I for liquid/vapor interface control was supported with System Safety criteria. The criteria is as follows:

1. Liquid/Vapor Interface Control

   In the selection of the type of liquid/vapor interface control to be accepted, the following safety considerations shall be utilized in the selection process.

   a. Rotational Method

      (1) The method shall consider the configuration and combinations of modules (add ons such as equipment module, LOX module, etc.) that will be docked and the potential hazards of CG excursion, introducing a wobble in the rotational plane during transfer of fluids.

      (2) The method shall consider the disturbance induced by coupling of the vehicle and propellant dynamics (sloshing) and the sensitivity of the RCS/stabilization sensing system to cope with the coupling disturbance of the various coupled configurations under normal and off design conditions of RCS operation.

      (3) The integrity of the system shall include the capability to assure the supply inlet shall be covered by fluid under sloshing conditions.

      (4) The rate of transfer of propellants shall consider the effect of laminar flow of propellants into the propellant tank, the sloshing created, and dynamics imparted to the configuration.

(5) The vehicle and propellant dynamic coupling during spin down of the configuration shall be considered for disturbance effects on the structural members.

(6) The time for emergency shutdown and spindown shall be considered for the case where a line rupture occurs at the line interconnect fixture, between transfer tanks.

(7) The effects of propellant tank venting during rotational transfer shall be investigated for potential ΔV introduction in an adverse thrust vector.

(8) During configuration rotation, no attached vehicle or module shall be manned.

b. Linear Acceleration Method

(1) The capability of the RCS to provide a stabilized configuration during linear acceleration along the longitudinal axis shall be such as to stabilize the configuration over the entire CG shift range during the transfer operation.

(2) Disturbances caused by sloshing or laminar flow injection into the receiver tank shall be considered for effects on the vehicles at initiation of transfer operations.

(3) Venting characteristics of the configuration during acceleration shall ensure an adverse ΔV thrust vector is not imparted to the configuration.

(4) The purging of fluids from transfer lines shall be accomplished during the acceleration mode.

(5) Emergency termination of the propellant transfer shall be considered for the case where a failure occurs at the line interconnect fixture.

c. Capillary Barrier Method

(1) Provide a means for preventing boiling in the capillary channels which will disrupt the flow of liquid.

(2) The sloshing of propellants during re-filling may wet a self-wicking screen, trapping any initial gas within the compartment. Safety consideration requires removal of trapped gasses.

(3) In assessing this method of liquid/vapor interface control, not only the effect of vapor control in the installed system must be considered, but also those effects and impact on the user vehicle for a full complement of capillary devices must be considered, where it is necessary to assure venting of gas for thermodynamic control.

(4) Consider the effect of propellant transfer slug flow and the effect of the flow on the capillary devices.

(5) This system is considered unusable and unsafe in the case where slush hydrogen is to be used in the tankage.

2. Receiver Tank Thermodynamic Control

a. Any tank thermodynamic control system shall include as a part thereof, a tank pressure relief system through which tank pressures can be vented automatically, by use of a vent valve, to maintain correct tank pressure.

b. In considering the case of venting to space, the effects of the vented fluid on operations in the area shall be such as to present no adverse effect on the operating systems, such as fogging TV lens, obscuring the area with ice crystals, etc.

3. Expulsion

a. In selection of the expulsion system, consideration of the rate of transfer vs. type of artificial "g" application should be evaluated for disturbance factors and CG migration/oscillation due to entry port location, laminar flow within the tank and rate of fluid entry.

b. The expulsion system shall be capable of becoming a receiver system in case of an emergency requiring shutdown of transfer and offloading of the intended receiver.

c. The expulsion system selected shall be capable of terminating transfer operations without fluid entrapment in any component or section. Purge and relief provisions are required.

d. Bladder material for bladder expulsion concepts shall be compatible with the fluid medium and be capable of operation without leakage of the fluids to the pressurization side of the bladder.

e. The material for use in bladder walls shall consider potential erosion factor under conditions where slush hydrogen may be created in tankage from inadvertent venting in space.

f. Any expulsion system shall include as a requisite, the capability of propellant flow measuring devices when used with the system.

g. Considerations for use of bellows as an expulsion device shall include the effects of ground checkout operations and maintenance interface when the tanks are empty or in a safing operation.

h. The capability of the expulsion system under pad abort conditions for emergency offload of the fluids shall be evaluated.

4. Pressurization

   a. The concept for liquid/gas conversion using a gas generator and pump shall consider the effects on the system due to potential instability. Erratic fuel flow to the pump could restrict the output head below the point where the heat exchanger could operate in a stable condition. The oscillations within the heat exchanger could create the instability.

   b. The pressurization concept shall include provisions for automatic termination and safing under emergency conditions.

   c. Pressurization concepts shall consider the range and rate of pressurization control needed for regulating pressures for large, small, lightweight, dewar-type tanks as well as maximum pressures for receiver and user vehicles. Effective use must not subject any of the tankage or vehicles to excessive pressures.

It should be noted that at the time of this criteria development, the use of a large storage facility was envisioned as a CIS/RNS and tug supportive depot. Thus Item 1.a(8) prohibited a vehicle from being attached during rotation of the configuration on the basis that disturbances could be generated which could subject the orbiter and crew to dynamic instabilities, coupling through structure with RCS reaction, and rotational wobble of the configuration.

When studies indicated no large depots were needed for the logistic system, this criteria was modified in the latter part of the study to require mated elements of the entire configuration to be man rated if the orbiter is attached during propellant transfer.

APPENDIX F

CONDITIONS CONTRIBUTING TO HAZARDS

A listing of conditions contributing to hazards of the Orbital Propellant Logistic Operations, as compared to those of other operations, is included for reference to the type of contributors involved.

1. Tank rupture causes fluids to mix, 4% H_2 - 2% O_2 minimum at 2 mm Hg or more pressure.
2. Line rupture, occurring when index probes did not release.
3. Uncontrolled impact ruptures tanks or lines and causes propellants to mix, 4% H_2 - 2% O_2 minimum and local pressures of 2 mm Hg or more.
4. Erratic fuel flow to Gas Generator (GG) liquid sloshing uncovers fuel inlet.
5. Instability of Heat Exchanger (H/E).
6. Structural failure due to over-all vehicle dynamic instability.
7. Improper control of GG regulators.
8. Fluids in cargo bay; hydrogen accumulates in cargo bay to 4% or more in air.
9. Loss of tank pressure causes implosion on re-entry.
10. Index probes fail to release.
11. Quick disconnect (QD) doesn't seat on separation.
12. QD damaged and leaks.
13. Electrical connector damaged.
14. Indexing probe fails to rigidize fixture.
15. Line extension bellows ruptures on actuation.
16. Failure to seal QD on mating.
17. Improper stowing, preventing line interconnect fixture mating.
18. Meteoroid penetration.

19. Penetration by space debris.
20. Venting in cargo bay during re-entry, releasing hydrogen.
21. Vent valve failure, tank overpressure blows rupture disc.
22. GG instability.
23. Loss of remote control of GG and H/E.
24. Thermal shock from tank, line rupture or vented gases.
25. Rapid chilldown of system.
26. Blowing leak cracks H/E or GG.
27. Impact during deployment when attached to manipulators.
28. Dynamic coupling.
29. Erratic operation of deployment mechanism.
30. RCS action when vehicles are captured but not rigidized.
31. Any condition leading to loss of vehicle control during transfer.
32. Separation attempts before complete docking release.
33. Failure to achieve rigidization during docking.
34. Intermittent RCS operation while docked to modular element.
35. Loss of vapor control.
36. Over pressurization.
37. Instability during rotational acceleration.
38. Instability during linear acceleration.
39. Boiling propellants in capillary channels.
40. Premature wetting of self-wicking screens.
41. Structural failure of capillary screens or baffles.
42. Buckling of positive displacement diaphragms.
43. Inability to purge positive displacement devices.
44. Leaking diaphragms or bellows.

45. Dynamic loading of interfaces.
46. Flex line rupture.
47. Uncoordinated manipulator movement.
48. Electrical connector failure.
49. Erratic operation of deployment mechanism.
50. Intermittent RCS with module on manipulators.
51. Impact from misalignment causes small mass to rotate.
52. Loss of docking interface rigidization.
53. Depletion of RCS propellants (tug).
54. Wobble during rotational transfer.
55. Loss of data on propellant quantity.
56. Structural failure during spin-up, despin.
57. Sloshing of propellants.
58. Propulsive Venting.
59. Propulsive leakage.
60. Misalignment of docking fixture.
61. RCS action with module extended on manipulator arms.
62. Failure of structural supports.
63. All the other hazards are contributors to degrading man rating when manned element is attached.
64. Failure of non-man rated systems with manned element attached.
65. Obscured vision.
66. Plume impingement.

APPENDIX G

SAFETY EVALUATION OF SLUSH HYDROGEN

INTRODUCTION

One of the considerations during the study was the possibility of delivering slush hydrogen instead of liquid hydrogen to the space-based vehicles. Since the hydrogen boiloff loss constitutes one of the major propellant losses during space storage, the use of slush hydrogen can reduce this loss by increasing the amount of heat absorbed by the bulk propellant before it reaches the saturation temperature. Slush hydrogen (SH_2) is a mixture of small solid hydrogen particles and liquid hydrogen which can be transferred much like a liquid. The mixture offers the advantage of substantially increasing the bulk propellant heat capacity which results in a potential reduction in boiloff losses. Additional advantages of slush hydrogen are an increase in bulk density, which suggests a smaller storage tank, and lower tank storage pressures resulting in reduced pressurization gas requirements. Consequently, the literature on slush hydrogen was reviewed and evaluated for potential hazards associated with application to propellant logistic programs.

HANDLING CHARACTERISTICS

Slush hydrogen must be aged for at least five hours so that handling characteristics will be consistent and accurately predictable. Small scale manufacturing and testing shows that 50 percent slush hydrogen can be handled much like liquid hydrogen except that continuous stirring may be required to prevent settling and an agglomeration of solid particles. Propellant loading into the propellant tank located in the cargo bay is discussed in Section 4, paragraph 4.2.1.2.

In both ground and orbital operations, an agglomeration of solid particles could be expected if continuous stirring or movement is not provided. Under any off specification condition for maintaining the desired mass fraction, hazards could be created. Hazards could be created in propellant lines and tanks, namely due to loss of ground thermal environment establishing two-phase flow, causing slugging and excess venting respectively. Clogging of the vent system in orbit could be expected due to formation of ice masses over the vent ports when the stirring is low and sloshing has occurred, or due to a zero "G" environment where the stirring device does not have the capability to stir properly due to the orientation of the slush hydrogen in the tank.

It can be postulated that in the event of an abort of the shuttle orbiter after liftoff and before attainment of orbit, the off loading of the slush hydrogen in the propellant tank module could present hazards. In systems where screens and/or baffles are used, the ice crystals of hydrogen may be collected on these surfaces and the liquid only off loaded by use of the

tank pressure. This could load the screens, bridge openings or cause failures of the mechanical systems which could preclude a safe abort. This condition will be similar in the case where the loss of insulation on the tank module provides a gross heat leak which requires emergency venting beyond the capability of the normal tank vent valve to relieve the expansion of the slush hydrogen.

The state-of-the-art for storage and handling of slush has not been extended beyond small-scale laboratory testing such that identification of hazards without a definitive system design has been based on the available aspects postulated from laboratory conditions.

Some of the postulated aspects where hazards could be generated in a slush hydrogen system for space vehicles could involve:

a. Compatibility with "In-Tank" Mechanical Devices

   Little is known of the effects of the interaction of zero "G" environmental sloshing and the bridging of solid hydrogen particles over such areas as vent valve tank outlets, gas generator line tank outlet, and fill and drain outlets. In the earth environment, the baffles and stirring system could present similar considerations. This effect (bridging) was noted by Charles W. Elrod in his large scale slush hydrogen production experiments, Tech Report AFAPL-TR-65-33 of July 1965.

   Additionally, in the case where the transfer system flow is terminated for a period of time such as a hold, loss of required thermal environment in localized areas of lines, could produce high localized pressures which could cause tank baffle damage when the flow is started again, due to slug flow.

b. Instrumentation and Measurement

   The requirements for instrumentation and measuring devices for a full-scale flight weight propellant tank module will present a design driver to propellant logistic transfer systems. The quantities of propellants transferred is a function of the solid mass fraction. While this can be determined during ground loading operations within prescribed limits, the capability to gage the quantities of propellants transferred in orbital operations is unknown and should be subjected to detailed analysis. While this aspect should not present any safety problems, the inability of the system to measure residual slush hydrogen accurately will present a major hazard. This hazard is associated with retrieval of the tank module for earth return in the shuttle orbiter cargo bay. If the quantity of residual propellants in the tank module cannot be measured accurately, loss of thermal protection insulation during re-entry could create an explosion due to excessive venting or tank over-pressurization, from flashing of residual propellants into a vapor.

c. Critical Flow Velocity as a Function of Pipe Diameter

Since this aspect is well documented (Reference 52) and design aspects known for preventing agglomeration of the ice particles it is not considered a safety problem. Operational problems could develop, however, which could be hazardous. This could be in the case where the facility loading lines failed to flow the slush hydrogen at the design velocity. It could be postulated that a line rupture could occur at a "hot" thermal leak point in the line.

d. Liquid/Ice Stratification in Deep Tanks

In a zero "G" environment with random movement of propellants, conditions could be created which were hazardous to internal tank systems. Ice chunks breaking off from baffles, wall, etc., could impact internal mechanical devices damaging the mechanism. This could be postulated to occur at docking impact.

e. Childown Aspects of Orbital Tanks

As a firm design of orbital tank systems is made for use with slush hydrogen, the operational aspects of childown procedures for initial orbital use should be evaluated for, among other things, conditions which could cause stressing of its components and lines.

f. Electrostatic Buildup

The quantity and effects of electrostatic charge generation during slush hydrogen transfer through long lines should be investigated. These effects should be considered for the docked configurations of space vehicles during transfer operations in orbit.

SAFETY EVALUATION

There does not appear to be any aspects of design of slush hydrogen systems which would preclude its safe use except in the area of thermal protection systems during ground operations for flight weight propellant tank modules.

In the literature there appears to have been much effort on storage of SH_2 in small quantities using Dewars. The flight weight thermal protection for flight weight tanks providing equal protection is non-existent. This is the area which will control the production of hazards in ground operations.

There also is no system which can provide accurate data on residual SH_2 quantities in orbital propellant tank modules. The quantity of these residuals must be known as they could impact the safe return of the tank in the shuttle orbiter cargo bay. Each tank will have to be designed for specification residuals. The residual propellants from a safety viewpoing involve tank pressure, vent size, vent actuation time, pressure relief system and emergency system. Loss of the thermal protection for the tank could cause over-pressurization of the tank during re-entry if residual propellants are more than design allowable.

The hazardous aspects associated with sloshing of propellants in zero "G" would be expected to diminish in orbital operations, except in those cases of docking impact.

CONCLUSIONS

a. In systems which are to be returned to earth such as propellant tank modules in the orbiter cargo bay, some extensive work is required to provide a technique for accurately determining residual propellants (slush hydrogen) after propellant transfer and prior to return to earth in the orbiter cargo bay.

b. The abort requirement for offloading slush hydrogen is a driver in the design for emergency dump systems for orbiter abort.

c. Continued study of hazards of using slush hydrogen should be made when the requirement for its use is firmed.

APPENDIX H

LITERATURE REVIEW REFERENCE

LITERATURE SEARCH

The following tabulation lists these documents that resulted from the literature search and were found to be most useful in the conduct of the study. Included in the tabulation is a one-sentence description of the main points brought out in the document.

Throughout this report these documents will be listed as the source from which information was derived, or used to substantiate a course of action. Even though there is no direct reference to an individual document they were included as being relative to the study since many were used to provide physical properties, operating conditions or background information.

1. Title: Analytical Approaches for the Design of Orbital Refueling Systems
   Author: G. W. Burge, J. B. Blackmon, R. A. Madsen (MDAC - S/M)
   Agency/Publisher: AIAA
   Document No.: Paper 69-567 Date: 6/9-13/69 Pages: 53 - 28 Ref

   The analytical tools available and experiments that need to be performed to define fluid propellant behavior in space.

2. Title: An Analysis of Potential Orbital Propellant Storage Requirements
   Author: W. E. Whitaker, MSFC
   Agency/Publisher: MSFC
   Document No.: TMX-64538 Date: 7-1-70 Pages: 19

   The starting point for studies relating to propellant requirements and modes of operation for orbital propellant storage for the near-term space program.

3. Title: AFSC Checklist of General Design Criteria
   Author: AFSC
   Agency/Publisher: AFSC
   Document No.: DH 1-X Date: 7-15-70 Pages: -

   System Safety guidelines and requirements by systems and subsystems in checklist form.

4. Title: AFSC Design Handbook, System Safety
   Author: AFSC
   Agency/Publisher: AFSC
   Document No.: DH 1-6 Date: 7-20-71 Pages: 300+

   System Safety guidelines and requirements in by systems and subsystems.

5. Title: Docking and Transfer Problem Survey
Author: Perry L. Gardner
Agency/Publisher: AIAA
Document No.: 69-1118 Date: Oct. 1969 Pages: 5

A generalized survey of the problems associated with the subject, many of which have been solved since the article was written.

6. Title: Cryogenic Solid Oxygen Storage
Author: John E. Ahern, Truman W. Lawson, Jr., AGC
Agency/Publisher: AMRL
Document No.: AMRL-TR-68-105 Date: Dec. 1968 Pages: 158

A study of the feasibility and desirability of using solid oxygen (SOX) to provide breathing oxygen for spacecraft crews.

7. Title: An Early Earth-Orbital Propellant Transfer Mission
Author: M. C. Ziemke, L. E. Toole, and T. F. Stomps (Chrysler)
Agency/Publisher: AIAA (Symposium on Missiles & Aerospace Vehicles)
Document No.: Vol. II Date: Dec. 1966 Pages: 81-1 to 81-12

A proposed earth-orbital propellant transfer mission using S-IVB hardware and linear acceleration for propellant settling.

8. Title: Electrostatic Hazards Associated with the Transfer & Storage of LH_2
Author: L. Cassutt, D. Biron, B. Vonnegut
Agency/Publisher: Advances in Cryo Engineering
Document No.: 4 Date: Pages: 327-336

Emphasized the requirement to keep all possible ignition away from H_2-O_2 mixtures.

9. Title: Evaluation of Experimental and Analytical Data for Orbital Re-fueling Systems
Author: C. C. Wood, H. F. Trucks
Agency/Publisher: AIAA
Document No.: 69-566 Date: 6/9-13/69 Pages: 11, 28 Ref

Outlines proposed project "Therms" to conduct orbital fluid transfer experiment to accumulate fundamental data on fluid behavior.

10. Title: An Experimental Study of Hydrogen Slush Pumping Characteristics
Author: L. A. Gross and C. D. Miller
Agency/Publisher: NASA/MSFC
Document No.: IN P&VE-P-68-3 Date: 12 Aug 1968 Pages: 21, 4 Ref

A report of the results of pumping tests at NBS, Boulder, Colorado

11. Title: Flow Research System for LH_2 and SH_2
Author: T. N. Marshall, Jr.
Agency/Publisher: Instr. Society of America
Document No.: 24th Conference Proceedings Date: 1969 Pages: 5

A large scale liquid and slush hydrogen production and flow facility system being built at MSFC to study production and transfer of slush.

12. Title: Fluid Hydrogen Slush - A Review
Author: G. A. Cook and R. F. Dwyer
Agency/Publisher: Advances in Cryo Engineering
Document No.: Vol. II Date: 1966 Pages: 202-206

A review of the properties and advantages of slush over liquid hydrogen.

13. Title: Generation and Loading of Triple Point Hydrogen for High Performance Aircraft, Boosters and Spacecraft
Author: N. E. Stanley (MDAC), C. W. Elrod (WPAFB)
Agency/Publisher: AIAA
Document No.: 67-468 (A67-33938) Date: July 1967 Pages: 9, 13 Ref

A report of the progress and data from two years of slush cryogen studies at WPAFB and MDAC.

14. Title: Handling Liquid Propellants
Author: Louis L. Dachs
Agency/Publisher: Space/Aeronautics
Document No.: Date: Oct. 1966 Pages: 7

A discussion of theoretical and practical fluid phenomena, including Zero G.

15. Title: Hazard Studies with H_2 and O_2 in the Liquid and Solid Phases
Author: S. Kay, GDC
Agency/Publisher: Advances in Cryo Engineering
Document No.: Vol. 11 Date: 1966 Pages: 277-86

A report of the ignition properties of hydrogen-oxygen mixtures at reduced pressures.

16. Title: High Altitude Explosion Properties of the H_2-O_2 System in Vented Tanks
Author: S. Kay, R. J. Murray
Agency/Publisher: Advances in Cryo Engineering
Document No.: Vol. 13 Date: 1968 Pages: 545-554

A report of the ignition properties of hydrogen-oxygen mixtures at reduced pressures.

17. Title: Hydrogen-Oxygen Reaction Studies, Final Report
Author: S. Kaye, J. Rosciszewski, R. J. Murray, J. G. Koency, G. T. Bayfield
Agency/Publisher: GDA
Document No.: GDC-DBE-67-016 Date: 9-67 Pages: 197

The results of study and experiments conducted by GDC on the reaction potential of hydrogen-oxygen under reduced pressure and various mixture ratios.

18. Title: Hydrogen-Oxygen Reaction Studies, Final Report
Author: S. Kaye, G. T. Bayfield
Agency/Publisher: GDA (MSFC Contr. NAS8-11405)
Document No.: DCN 1-4-96-01009-01 Date: 12/65 Pages: 407

The results of study and experiments conducted by GDC to assess the nature and extent of the detonation or explosive hazards of the hydrogen-oxygen system at reduced pressures.

19. Title: Integrated Space Program and Vehicle Systems Analysis - Study "B"
Author: Aerospace Corp.
Agency/Publisher: Final Report to be ATR-71(7232)-5
Document No.: Final Monthly Report Date: 6-30-71 Pages: 96

Includes a discussion of "On-Orbit Testing" and potential problems associated with maintenance and assembly.

20. Title: Investigation of the Effects of Vacuum on LH_2 and Other Cryogens Used on Launch Vehicles (Final Report)
Author: J. A. Simmons, R. D. Gift, M. Markels, Jr. (Atl. Res.)
Agency/Publisher: Atlantic Research Corp. (Contr. NAS8-11044

The reaction of liquid propellants on exposure to simulated space conditions.

21. Title: Liquid Hydrogen Technology
Author: R. T. Parmley
Agency/Publisher: GDA
Document No.: Report #AE62-0774 Date: Sept. 1962 Pages: 294

The properties of liquid hydrogen, including a section on Zero G behavior and space storage.

22. Title: Liquid Propellant Handling, Storage and Transportation
Author: JANNAF Hazards Working Group
Agency/Publisher: CPIA
Document No.: 194 Vol. 3 Date: April 1970 Pages: 412

General ground handling of liquid propellants.

23. Title: Liquid-Solid Mixtures of Hydrogen Near the Triple Point
Author: P. B. Mann, P. R. Ludtke, C. F. Sindt, D. B. Chelton
Agency/Publisher: Advances in Cryo Engineering
Document No.: Vol. 11 Date: 1966 Pages: 207-217

A report on the work on slush hydrogen that occurred at NBS Boulder, Colorado.

24. Title: Maintainability of Manned Spacecraft for Long Duration Flights
Author: Boeing
Agency/Publisher: Boeing
Document No.: D2-113204-1 B/1 Date: Aug. 1968 Pages: 57 (Vol. 1)

A thorough analytical study of the 1975-85 space program maintenance, maintainability and spares requirements.

25. Title: Manned Spacecraft Criteria and Standards
Author: MSC
Agency/Publisher: MSC
Document No.: MSCM 8080 Date: 11-2-71 Pages: 137

Design and operating standards based on experience.

26. Title: Nuclear Flight System Def. Study (RNS) - Subsystems
Author: D. Garcia
Agency/Publisher: NR/SD
Document No.: SD70-117-4 Vol. IV Sys. Def. Date: Apr. 1970 Pages: 360

Includes a section on orbital and ground propellant handling and conditioning.

27. Title: On-Orbit Maintenance of the Orbit-to-Orbit Shuttle
Author: J. H. Todd
Agency/Publisher: Aerospace
Document No.: TOR-0059(6531-03)-1 Date: 3-15-71 Pages: 57

Space is a hostile environment to man and therefore he must employ new concepts and techniques for maintenance.

28. Title: An Orbital Maintenance and Material Transfer Shuttle, A study of
Author: Ray Goodall
Agency/Publisher: LMSC
Document No.: RTD-TDR-63-4057 Date: 3-64 Pages: 356

Study concluded that such a vehicle is possible and only one man is needed to use it.

29. Title: Orbital Operations Study, Orbital Interfaces Operations Tradeoffs and Analysis
Author: L. R. Hogan
Agency/Publisher: NR/SD
Document No.: SD72-SS-0001 Date: 1-72 Pages: 300+

A study of the 14 interfacing activities of orbital operations.

30. Title: Orbiting Propellant Depot for Chemical Orbit-to-Orbit Shuttle
Author: L. L. Schilb
Agency/Publisher: Aerospace
Document No.: TOR-0059(6758-01)-16 Date: 5 Oct. 1970 Pages: 21

A preliminary study of the requirements for an OPD.

31. Title: Orbiting Propellant Depot Safety Study
Author: R. R. Wolde
Agency/Publisher: Aerospace
Document No.: ATR-71(7233)-3 Vol. II Date: 1971 Pages: 70

A directly applicable study of the safety considerations of an OPD.

32. Title: Orbital Refueling and C/O Study
Author: J. P. Claybourne
Agency/Publisher: LMSC
Document No.: TI-51-67-21 Date: 2-12-68 Pages: 145

An analysis of orbital propellant transfer was selected by computer from 22000 different possible combinations.

33. Title: Orbital Refueling Techniques
Author: J. E. Boretz (TRW)
Agency/Publisher: Journal of Spacecraft and Rockets
Document No.: AIAA A70-30752 Date: May 1970 Pages: 513-522

This paper reviews the more feasible and promising concepts for propellant transfer in orbit, analytical and theoretical.

34. Title: Orbital Storage of Liquid Propellants
Author: P. Oberding
Agency/Publisher: Reaction Motors
Document No.: RMD-23005-126 Date: 4-17-64 Pages: 39

The heating rate of orbiting bodies.

35. Title: Orbital Tanker Design Data Study
Author: L. L. Morgan, et al
Agency/Publisher: LMSC
Document No.: LMSC-A748410 Vol. I, Summary Date: 30 May '65 Pages: 49

Establishes the practicality of orbital propellant transfer.

36. Title: Orbiter Vehicle Prime Item Specification, Part I, Space Shuttle System
Author: NR/SD
Agency/Publisher: NR/SD
Document No.: Spec. #CP613M0002 Date: 3-26-71 Pages: 213

This specification establishes the requirements for the performance, design, development, and test of the 161C shuttle orbiter.

37. Title: Parametric Studies or Orbital Fluid Transfer
Author: L. L. Morgan (LMSC)
Agency/Publisher: AIAA
Document No.: 69-565 Date: 6-69 Pages: 5

A summarization of the results obtained during "Orbital Refueling and Checkout Study."

38. Title: Phase B Final Report Expendable Second Stage, Reusable Space Shuttle Booster
Author: NR/SD
Agency/Publisher: NR/SD
Document No.: SD71-140-2 Date: 6-25-71 Pages: 300+

The use of an ESS to place payloads of greater than 100K pounds into earth orbit.

39. Title: Pre-Launch Slush H_2 Loading Factors Affecting Instrumentation and Control
Author: R. M. Kocher and C. W. Keller (LMSC)
Agency/Publisher: Advances in Cryo Engineering
Document No.: Vol. 14 Date: 1969 Pages: 306-310

A discussion of the instrumentation requirements of handling slush hydrogen.

40. Title: A Preliminary Study of the Orifice Flow Characteristics of Liquid N_2 and LH_2 Discharging into a Vacuum
Author: J. A. Brennan
Agency/Publisher: Advances in Cryo Engineering
Document No.: Vol. 9 Date: 1965 Pages: 292-303

Relevant information is contained on the leakage of propellants into space vacuum.

41. Title: Preparation and Characterization of Slush Hydrogen and Nitrogen Gels
Author: D. E. Daney and A. S. Rapial
Agency/Publisher: Advances in Cryo Engineering
Document No.: Vol. 15 Date: 1970 Pages: 467-475

Additional details of slush production and study that has been going on at NBS Boulder for a number of years.

42. Title: Preparation and Characterization of Slush H_2 and N_2 Gels
Author: A. S. Rapial and D. E. Daney
Agency/Publisher: NBS, Boulder
Document No.: Tech Note 378 Date: May 1969 Pages 40, 9 Ref

A formal report of slush production and study that has been going on at NBS Boulder for a number of years.

43. Title: Proceedings - Space Transportation System, Propulsion Technology Conference
Author: --
Agency/Publisher: MSFC
Document No.: Vol. IV Cryogens Date: 4-6,7 1971 Pages: 1265-1500

Papers presented on orbital propellant transfer, Zero "G" behavior and insulation performance.

44. Title: Proceedings of the Conference on Long-Term Cryo-Propellant Storage in Space
Author: Various
Agency/Publisher: NASA/MSFC (TMX #60666)
Document No.: X68-10323 to X68-10343 Date: Oct. 12,13-66 Pages: 254

Twenty papers on thermal properties and fluid behavior of propellants in orbital environment.

45. Title: Propellants and/or Service Depot Safety Study
Author: H. Yoshikawa
Agency/Publisher: Aerospace Corp.
Document No.: Task CII Monthly Reports Date: 8/70, 9/70, 10/70, 11/70, 1/71, 2/71, 4/71, 6/71
Pages: Various

The monthly reports that make up the final report, "Orbiting Propellant Depot Safety Study."

46. Title: Propellant Delivery
Author: G. S. Mattingly
Agency/Publisher: ERA (Environmental Research Associates)
Document No.: NASA/MDAC Cargo/Pkg. and Handling Conf.
Date: Aug. 3,4, 1970 Pages: 259-270

Top level review of the problems associated with delivering propellants to orbital users.

47. Title: Propellant Position Control by Capillary Barriers During Spacecraft Rotational Maneuvers
Author: D. F. Gluck, NR
Agency/Publisher: J. Spacecraft
Document No.: Vol. 7 #3 Date: 3-70 Pages: 242-247

Analytical, considers propellant settling by rotation only.

48. Title: Safety Analysis of Parallel Vs. Series Propellant Loading of the Space Shuttle
Author: O. Hambert, F. D. Tomlinson
Agency/Publisher: Aerospace Corp.
Document No.: ATR-71(7233)-1, Vol. I and II Date: 6/30/71
Pages: 16 and 48

Concluded that series loading was less hazardous than parallel loading and, since time lines would permit, the shuttle should be loaded in series.

49. Title: S-II Stage Orbital Propellant Storage System Feasibility Study
Author: NR/SD
Agency/Publisher: NR/SD
Document No.: SD70-554-2 Date: 3-31-71 Pages: 721

An orbiting depot to supply propellants to other orbiting vehicles is technically feasible.

50. Title: Second National Conference on Space Maintenance and Extra-Vehicular Activities
Author: Various
Agency/Publisher: USAF/NASA/NR-SD
Document No.: -- Date: Aug. 6-8, 1968 Pages: --

Several articles in the field of interests covered by the subject of the conference.

51. Title: Shuttle Orbital Applications and Requirements, SOAR/Shuttle Data Book
Author: MDAC
Agency/Publisher: MDAC
Document No.: MDC G2327 Date: Pages: --

Presenting a description of the capabilities of the MDAC MP-8A shuttle to accommodate, support, deliver, and retrieve the variety of payloads being considered in the SOAR study.

52. Title: Slush H_2 Flow Characteristics and Solid Fraction Upgrading
Author: C. F. Sindt, P. R. Ludtke (NBS)
Agency/Publisher: Advances in Cryo Engineering
Document No.: Vol. 15 Date: 1970 Pages: 382-390

Discusses the phenomena of "critical flow" in moving slush.

53. Title: Slush Hydrogen Production, Storage, and Distribution Study Program
Author: C. F. Fails, C. R. Baker, J. D. Brunt, R. A. Pike, G. A. Cook, L. C. Matsch, L. C. Kun
Agency/Publisher: Union Carbide
Document No.: NASA CR 81185 Date: May 13, 1966 Pages: 96

A study to determine most efficient plant to produce 18 tons per day of hydrogen slush at Jackass Flats.

54. Title: Slush H_2 Pumping Characteristics Using a Centrifugal Type Pump
Author: D. E. Daney, P. R. Ludtke, C. F. Sindt
Agency/Publisher: Advances in Cryo Engineering
Document No.: Vol. 14 Date: 1969 Pages: 438-445

Slush Hydrogen pumping study conducted at NBS, Boulder, Colorado

55. Title: Slush and Subcooled Propellants for Lunar and Interplanetary Missions
Author: J. L. Vaniman, A. L. Worlund, T. W. Winstead, NASA/MSFC
Agency/Publisher: Advances in Cryo Engineering
Document No.: Vol. 14 Date: 1969 Pages: 20-29

Slush and subcooled cryogens can extend capabilities of current launch vehicles.

56. Title: Solidified O_2 for Breathing in Space
Author: N. Plaks (AGC), K. Weiswurm (WPAFB)
Agency/Publisher: Advances in Cryo Engineering
Document No.: Vol. 13 Date: 1968 Pages: 430-437

Experimental and analytical study of SOX.

57. Title: Space Mission Duration Extension Problems, A Study of
Author: R. B. Carpenter, Jr.
Agency/Publisher: NR/SD
Document No.: SD67-478-3 Date: Oct. 1967 Pages: --

An analytical study.

58. Title: Space Shuttle Phase B Final Report Volume II, Technical Summary, Book 3, Booster Vehicle Definition
Author: NR/SD
Agency/Publisher: NR/SD
Document No.: SD71-114-2(3)(MSC-03307) Date: 3-26-71 Pages: 300+

This book defines the configuration and operation of the B-9 Booster.

59. Title: Space Shuttle Phase B Final Report Volume II, Technical Summary, Book II, Orbiter Vehicle Definition
Author: NR/SD
Agency/Publisher: NR/SD
Document No.: SD71-114-2(2)(MSC-03307) Date: 3-26-71 Pages: 300+

This book presents the 161C orbiter and requirements, general arrangement, mass properties flight operational and performance characteristics, subsystems definition and functional interfaces and manufacturing approach.

60. Title: The Space Simulators of O.N.E.R.A.
Author: Jean Suruget, Marcel LeMignon
Agency/Publisher: Spaceflight
Document No.: -- Date: -- Pages: 250-255

French space environment simulators.

61. Title: Space Station Safety Study (MSC-00189) Crew Safety Guidelines, Vol. I and II
Author: E. L. McCabe, E. P. Goodrich, W. N. Gilbert
Agency/Publisher: Boeing
Document No.: D2-113070-5 Date: 1-70 Pages: 395

A thorough system safety analysis of the Space Station.

62. Title: STS Propellant Loading System
Author: --
Agency/Publisher: Aerospace Corp.
Document No.: 69-5111.17-18, 70(5758-03)-8 Date: 1970 Pages: 27

A study to determine if the specified two-hour reaction time is adequate to load propellants on the STS.

63. Title: A Study of Human Performance in a Rotating Environment
Author: J. A. Green, J. L. Peacock, A. P. Holm
Agency/Publisher: NR/SD
Document No.: SD70-456, NASA CR 111866 Date: 1971 Pages: 233

The results of a series of tests on human subjects in a rotating facility.

64. Title: A Study of Hydrogen Slush and/or Hydrogen Gel Utilization
Author: C. W. Keller (LMSC)
Agency/Publisher: LMSC
Document No.: K-11-68-1K Date: 31 Oct. 1968 Pages: Vol. I - 76
Vol. II-136

A discussion of the benefits to be derived by the use of slush.

65. Title: A Study of Space Mission Duration Extension Problems
Author: R. B. Carpenter, Jr.
Agency/Publisher: NR/SD
Document No.: SD67-478-3 Date: 10-30-67 Pages: 350

An analytical study.

66. Title: A Study of Teleoperator Technology Development and Experiment Programs for Manned Space Flight Applications
Author: A. Interian (GE)
Agency/Publisher: GE, SSO Date: 1-15-71 Pages: 300+

This study continues previous industrial work in applying teleoperator systems and identifies the technology required to develop teleoperator applications for manned space flight.

67. Title: A Summary of the Characterization Study of Slush H_2
Author: C. Sindt
Agency/Publisher: Cryogenics
Document No.: -- Date: Oct. 1970 Pages: 372-380

A review article of the benefits of using slush.

68. Title: System Requirements, Mission Capability and Operations Analysis - S-II Stage Interorbital Shuttle Capability Analysis
Author: NR/SD
Agency/Publisher: NR/SD
Document No.: SD71-245-2 Date: 2-71 Pages: 300+

A CIS can meet program and operations requirements.

69. Title: Systems Safety Guidelines of New Space Operations Concepts - Space Shuttle Program
Author: W. L. Finch, D. A. Smith
Agency/Publisher: LMSC
Document No.: LMSC-A968322 Date: 7-70 Pages 31, 136

A system safety analysis of the space shuttle.

70. Title: System Safety Requirements for Manned Space Flight
Author: MSC
Agency/Publisher: MSC
Document No.: SPD-1A Date: 12-12-69 Pages: 8

Establishes System Safety methodology for space programs.

71. Title: Systems Safety for Manned Operations in Earth-Orbital Missions
Author: G. S. Canetti
Agency/Publisher: NR/SD
Document No.: SD71-230 Date: 7-15-71 Pages: 10

This paper describes how System Safety considerations have influenced the operations, configuration and design of manned earth orbital elements.

72. Title: Technical Proposal for Low Gravity Propellant Transfer
Author: R. A. Beaudreau, D. F. Gluck, et al
Agency/Publisher: NR/SD
Document No.: DNO 70-190, SD70-72 Date: 3-19-70 Pages: 74

A proposal to perform an analytical study of potential methods of replenishing the APS, ECLSS, and fuel cell storage tanks.

73. Title: Testing of a Cryogenic Propellant Subsystem in a Simulated Space Environment
Author: T. J. Kelley, USAF
Agency/Publisher: AFRPL Date: 3-70 Pages: 88

Description of techniques of use and design of space simulators.

74. Title: TNT Equivalency Study for Space Shuttle
Author: R. R. Wolfe
Agency/Publisher:
Document No.: ATR-71(7233)-4, Vol. I, II, III
Date: Pages:

This study re-evaluates the existing TNT equivalency criterion for LO_2/LH_2 propellant.

75. Title: Use of Man in Space
Author: B. Howard and G. T. Orrok (Bellcomm)
Agency/Publisher: AIAA
Document No.: 69-1045 Date: Oct. 1969 Pages: 8

Explores the questions of when and where to use man instead of machines in space.

76. Title: Use of Slush H_2 for the Propulsion of Spacecraft
Author: D. Chain
Agency/Publisher: Assn. Francaise des Ingenieurs et Technicians
Document No.: NASA TTF-12,827 Date: 6/2,4/69 Pages: 14

A French study was conducted to explore the advantages and disadvantages of hydrogen slush.

ADDENDA

The below listed documents which provided information that was relative to the In-Space Propellant Logistics & Safety Study were received incrementally throughout the study, after compiling the results of the original Literature Survey.

1A. Title: Acoustic Pumping for Propellant Management in Space
Author: P. S. Wessels
Agency: GDC, Pomona
Publisher: Space/Aeronatics
Document No.: Date: 6/69 Pages: 75-77

A light-weight propellant settling technique using acoustic energy to drive propellants away from the sound source is under development at GDC.

2A. Title: An Analysis of the Dynamics and Thermodynamics of Water and Oxygen Particles in Space Based on Photographs Taken from the Ground During Apollo Missions
Author: R. D. Sharma, M. L. Kratage (Bellcomm)
Agency/Publisher: AIAA
Document No.: 71-474 Date: 4/26-28/71 Page: 6

Observations of the venting of fluids from S-IVB during various Apollo missions.

3A. Title: Application of Heat Pipes to Reduce Cryogenic Boiloff In Space
Author: J. L. Thurman and E. H. Ingram
Agency: Brown Engineering, Huntsville
Publisher: Journal of Spacecraft and Rockets
Document No.: Date: 3/69 Pages: 319-321

A proposal to use structures of very high heat conductance to transfer heat between source and sink to reduce boiloff in space.

4A. Title: Contamination Sensitivity Analysis
Author: G. L. Wengrow
Agency/Publisher: NR/SD
Document No.: 192-500-CWR-72-019 Date: 1/24/72 Page: 22

A discussion of potential contamination of shuttle carried experiments with the conclusion that problems from deposition of materials onto sensitive surfaces are potentially serious.

5A. Title: Dielectrophoretic Liquid Expulsion
Author: Melcher et al
Agency: M.I.T. and Dynatech
Publisher: J. Spacecraft and Rockets
Document No.: Date: 9/69 Pages: 961-967

Experimental data presented to settle propellants by means of an electric field.

6A. Title: Lightweight Multilayer Insulation System. Final Report (NASA-CR-72363)
Author: C. R. Lindquist and G. E. Nies
Agency: Linde Company
Document No.: Date: 2/23/68 Page: 194

The development and testing of a shingled multi-layer system on a 30-inch diameter liquid hydrogen tank that resulted in a heat flux of 0.63 Btu/hr. ft^2 for in-space conditions and 10 Btu/hr. ft^2 for ground hold.

7A. Title: Nuclear System Safety - Transportation by Earth Space Shuttle
Author: E. Gerrels, et al
Agency/Publisher: G.E. NSP
Document No.: GESP-7068 Date: 10-21-71 Page: 156

Final performance review of Contract NAS8-26283

8A. Title: Orbital Storage of Liquid Propellants
Author: P. Oberding, S. J. Tick
Agency/Publisher: Reaction Motors, Thiokol
Document No.: RMD 23005-126 Date: 4/17/64 Page: 39

A fundamental study of the calculation of the heat flux incident on a propellant storage tank in the space environment in the vicinity of a planet.

9A. Title: Orbit-to-Orbit Shuttle Propellant Integration and Handling Study
Author: D. A. Heald, G. R. Stone, S. Kaye (GDC)
Agency/Publisher: AFRPL (Contract F04611-70-C-0087)
Document No.: GDC-BMZ70-013-18 Date: 12/71 Page: 253

This study examines the hazards inherent in the design and operation of ground and vehicle systems for a liquid fluorine space vehicle.

10A. Title: Setting the Structural Design Criteria for Space Debris Effects in Cislunar and Outer Space Travel
Author: Sydney D. Black (Republic)
Agency/Publisher: Society of Automotive Engineers
Document No.: 520E Date: 4/3/62 Page: 14

Evaluating the limits to be set in material selection and structural design so that the existing space debris environment can be tolerated by a space vehicle.

11A. Title: Space Base Nuclear System Safety Study
Author: E. Gerrels, et al
Agency/Publisher: G.E. NSP
Document No.: GE-SP7059 Date: 11/24/70 Pages: 300

First performance review that outlines the course of the study.

12A. Title: Space Rescue Considerations
Author: Rodney G. Rose (NASA, Houston)
Agency/Publisher: NASA
Document No.: MSC-04901 Date: 9/20/71 Pages: 41

The rescue requirements for earth-orbiting vehicles in the post-skylab era are examined, with causes of occurrence and rescue time considered.

13A. Title: Space Tug, Point Design Study, Final Report, Vol. III Design Definition
Author: NR/SD
Agency/Publisher: NR/SD
Document No.: SD72-SA-0032 Date: 2/11/72 Pages: 300+

Verified through detail design and analysis the capability to deliver and retrieve a 3720-pound payload to a geosynchronous orbit from a low earth orbit and a mass fraction of better than 0.90.

14A. Title: Testing of Polymeric Materials for Use in Multiple-Ply Expulsion Bladders for Cryogenic Liquids
Author: P. H. Pope and J. E. Penner
Agency: Beech Aircraft, Boulder
Publisher: Journal of Spacecraft
Document No.: Date: 3/68 Pages: 259-264

As a result of testing it is concluded that polymeric expulsion bladders are feasible for the isolation of pressure source and cryogenic fluids.

15A. Title: Zero-g Hydrogen Tank Venting System
Author: R. C. Mitchell, et al
Agency: GDC
Publisher: Advances in Cryo Engineering, Vol. 12
Document No.: Date: 6/66 Pages: 72-81

A paper describing the results of a study conducted for NASA to determine the relative merit of several methods to separate liquid and gas for venting liquid hydrogen tanks.

16A. Title: Zero-g Propellant Gauging of Cryogenic
Author: R. G. Morrison
Agency: TRW Systems Group
Publisher: NASA, N71-35036
Document No.: Date: 5/11-13/71 Pages: 37-52

Investigation of techniques (other than RF) of measuring the quantity of cryogenics in a tank at zero-g indicates that nucleonic systems offer the most promise.

17A. Title: Zero-g RF Gaging System
Author: H. E. Thompson, NASA, N. E. Stanley, et al, Bendix
Agency/Publisher: NASA
Document No.: N71-35037 Date: Pages: 53-72

Experimental evidence indicates that RF gauging systems are feasible for measuring the quantity of cryogenic fluids in a tank at accuracies in the range of 1 to 2.7%.

APPENDIX I

LIST OF ABBREVIATIONS AND DEFINITIONS

ACPS	Attitude Control Propulsion System
ACS	Attitude Control System
APU	Auxiliary Power Unit
BSP	Study Baseline Space Program
CIS	Chemical Interorbital Shuttle
DMS	Data Management System
DRS	Data Relay Satellite
ECS	Environmental Control System
ECLSS	Environmental Control and Life Support System
ESS	Expandable Second Stage
G&C	Guidance & Control
GG	Gas Generator
GLR	Guideline/Requirement
GN&C	Guidance, Navigation and Control
IMU	Inertial Measuring Unit
IU	Instrument Unit
LOW	Liftoff Weight
LSF	Large Storage Facility
LSS	Life Support System
NPSP	Net Positive Suction Pressure
mm	Millimeter
n mi	Nautical Miles
NR	North American Rockwell Corporation
OBCO	Onboard Checkout
OMS	Orbital Maneuvering System
OPD	Orbital Propellant Depot (also called Depot)
OPSS	Orbital Propellant Storage System
PLSS	Portable Life Support System
RCS	Reaction Control System
RNS	Reusable Nuclear Shuttle
SLR	Scanning Laser Radar
SH_2	Slush Hydrogen
SS	Space Shuttle
TUG	Space Tug

Docking Section	That part of the Depot containing the Docking Ports
Assembly Ports	Those Docking Ports to which segments that comprise the Depot are docked.
Docking Ports	Those Docking Ports made up of large structural mechanism to which user and supplier vehicles are connected for servicing
Soft Docking	Docking by use of manipulators
Hard Docking	Docking by alignment of docking elements by use of propulsive devices
Series Loading	Loading propellants, where the oxidizer is loaded first and fuel is loaded second in a non-overlapping time interval
Parallel Loading	Loading both oxidizer and fuel during the same time interval
Free Volume	The net volume of the cargo bay, minus the colume of the cargo. This is the volume that is available in which to mix the leaking hydrogen with air to form reaction mixture.
Blowing Leak	A leak that exceeds allowable or specification limits
Functional Flow Diagram	A map of events leading to an end, showing the sequence and interrelationships of events to accomplish the end.
GSE	Ground Support Equipment
Hydrogen Slush (Slush Hydrogen)	A mixture of small, solid hydrogen particles suspended in liquid hydrogen at the triple point.
Propellant Logistics System	That system which incorporates the transport from ground to space, transfer, and orbital storage (if required) for the purpose of propellant resupply of space-based user vehicles.
Modular Transfer	The package exchange of cargo (fluids); i.e., the replacement of an empty tank by a like tank that is full.

Orbital Storage	Sometimes referred to as storage. The accumulation and maintenance (saving) of fluid in earth orbit for subsequent transfer to a user vehicle.
Sortie Module (Manned, Free-flying)	A reusable space laboratory that will house personnel while they conduct short-duration experiments in earth orbit.
Liquid/Vapor Interface Control	Management of the position in the tanks of the liquid to vapor boundaries
Propellant Logistics Module	Propellant tank and associated hardware fitting the shuttle orbiter cargo bay and employed for transporting propellant to the user vehicles
Storage	See orbital storage
Timelines	A sequence of activities in a mission with start and stop times (duration) of the activity defined.
Transfer	The exchange of propellant or fluid from one vehicle or spacecraft to another vehicle or spacecraft.
Tug	Upper stage vehicle sized to be transported to earth orbit by a space shuttle orbiter.
User Vehicle	A space-based spacecraft which requires propellant refueling or makeup of life support fluids in earth orbit.
Rotational Propellant Transfer	Rotation of the propellant source tank and receiver tank about a pitch axis to settle propellants by the resulting acceleration forces and permit fluid pumping.
Linear Propellant Transfer	Acceleration of source tank and receiver tank in X axis direction and permit fluid pumping.